



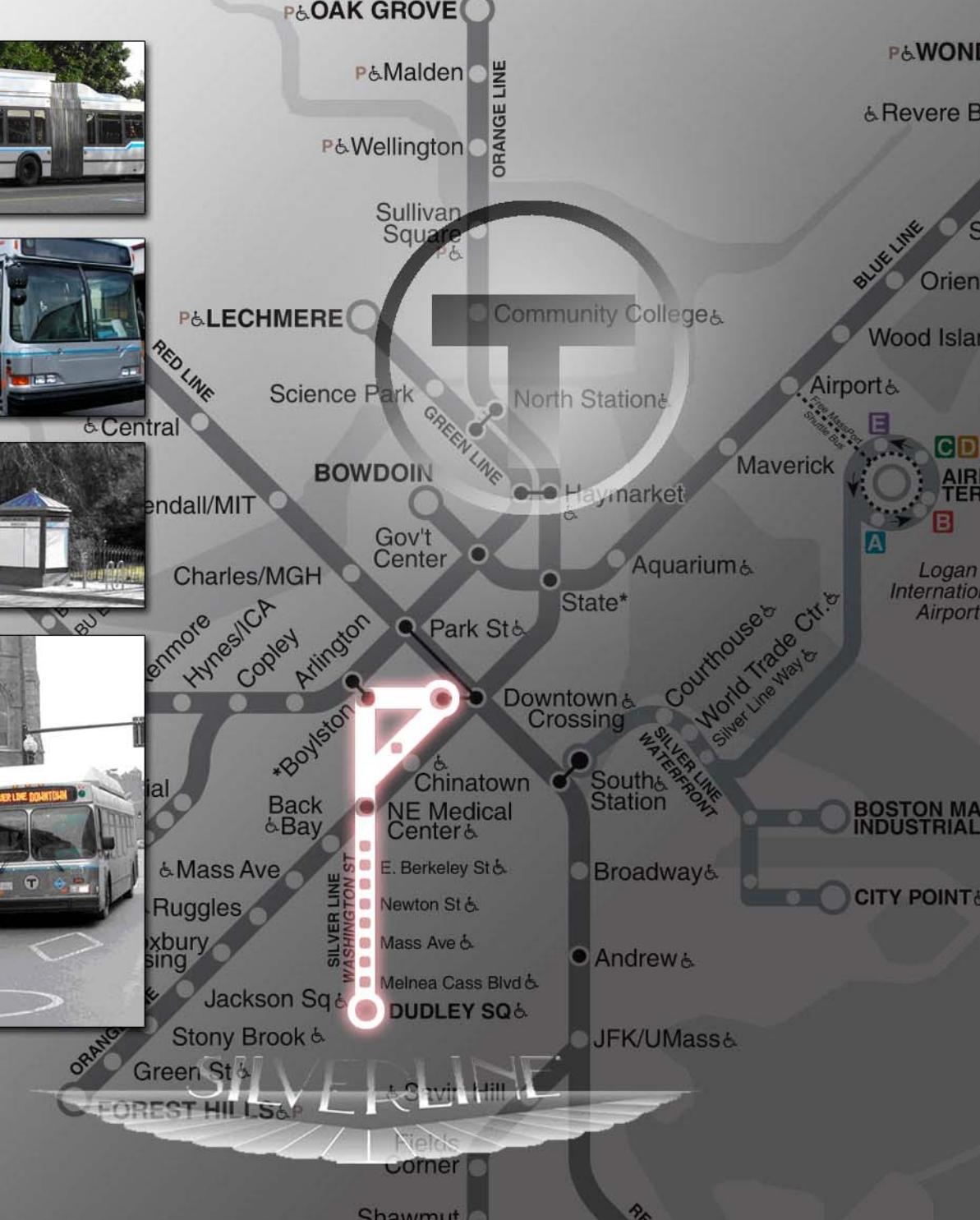
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September 2005

Boston Silver Line Washington Street Bus Rapid Transit (BRT) Demonstration Project Evaluation



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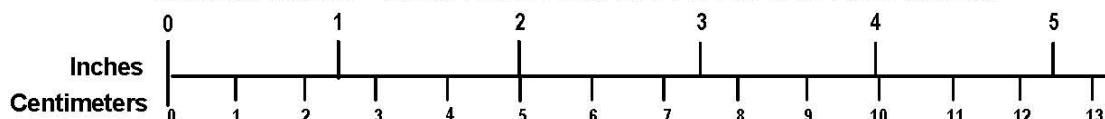
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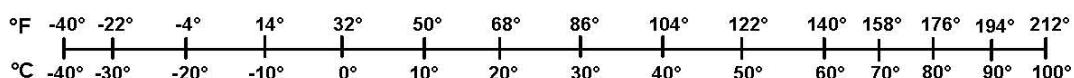
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1.0 INTRODUCTION

This research study is supported through the Federal Transit Administration's Bus Rapid Transit (BRT) Initiative, which investigates the technologies and advanced operational capabilities of BRT systems and facilitates the implementation of successful BRT projects throughout the United States. The specific objectives of FTA's BRT Initiative are to:

- Improve bus speeds and schedule adherence
- Increase ridership as a result of improved quality of service that encompasses bus speeds, schedule adherence and convenience
- Minimize the effect of BRT on other traffic
- Isolate the effect of each BRT feature on bus speed and other traffic
- Assess the benefits of Intelligent Transportation Systems/Automated Public Transportation Systems

Additionally, the BRT Initiative aims to provide positive impacts on local businesses, determine the benefits of ITS technologies, and evaluate the effects of BRT systems on land development.

This study presents a detailed evaluation of Massachusetts Bay Transportation Authority's (MBTA) first BRT project, Silver Line Washington Street. This project, combined with a second phase, Silver Line Waterfront, is one of the national demonstration projects sponsored by the Federal Transit Administration's BRT Initiative. The data presented in this evaluation were collected according to the Silver Line Data Collection Plan dated October 15, 2004. This report presents the data collected to date since evaluation activities commenced on July 7, 2004. This Evaluation Report covers only Phase I of the project, Washington Street. Phase II of the project, which had an interim opening on December 17, 2004, was covered in the Data Collection Plan, but will be the subject of a separate evaluation report.

In accordance with the evaluation framework outlined in the Characteristics of Bus Rapid Transit for Decision-Making (CBRT) report, this evaluation is organized into the following sections:

- Project Context
- Project Description
- System Costs
- Planning, Design and Implementation
- Evaluation of System Performance
- Assessment of System Benefits
- Conclusions

This evaluation finds that Silver Line Washington Street is an example of how a comprehensive systems approach to BRT implementation can result in the achievement of a broad array of system performance objectives – including higher ridership, reduced travel time, enhanced safety and security, and higher customer satisfaction. These project benefits correspond directly with several of the FTA Strategic Goals. BRT systems enhance the transit experience and can be flexibly adapted to a multitude of urban environments. These systems can be incrementally and economically scaled upwards to meet future demand.

1.1 PROJECT CONTEXT AND OVERVIEW

Silver Line Washington Street, formerly called Phase I, and originally the “Washington Street Replacement Project,” provides service from Dudley Square to Downtown Boston in an at-grade alignment, operating mostly in a combined bus and right-turn only lane but also in mixed traffic and a short segment of exclusive contraflow lane. It opened for service in July, 2002.

Silver Line Washington Street is a replacement for MBTA bus route 49, which operated in roughly the same alignment. The changes that transformed the 49 into the Silver Line were not all implemented at the same time. In December 2001, a contraflow lane on Washington Street outbound (south) was opened. This enabled bus route 49 to eliminate an indirect routing several blocks long and to serve the New England Medical Center (NEMC) on outbound trips. At the same time, the frequency of service was increased. The official launch of the Silver Line took place on July 20, 2002. On this date the new low-floor CNG buses in Silver Line livery were deployed and the number of stops was reduced to 11 (from 20) in each direction. In November 2002, one of the deleted stops (Worcester Square) was restored. Beginning in August 2003, 60-foot articulated buses began to replace 40-foot buses, and the service frequency was increased. In late January, 2005, the buses were equipped with new automatic fare collection (AFC) equipment as part of a pilot test of a system-wide deployment of the AFC system. The real-time passenger information and traffic signal priority systems have been tested but at the time of this evaluation have not been fully implemented.

Silver Line system features include:

- A transit lane along most of the route
- More direct routing due to contraflow lane
- 100% low floor vehicles
- Enhanced passenger stations
- Fewer stops
- Traffic signal priority (future implementation)
- Computer Aided Dispatching and Automatic Vehicle Location systems
- Real-time passenger information (future implementation)

The MBTA is responsible for a large and multi-modal system. In 2003, the MBTA operated 5.2 million vehicle revenue hours and had 389 million passenger boardings. The largest share, 39% of boardings, were on heavy rail. Bus and trolleybus had 32%, light rail 19%, and commuter rail 10%. The remaining boardings were on demand response and ferryboat (National Transit Database, 2003 Profiles, 30 Largest Agencies). Many passenger trips on the MBTA involve the use of more than one mode.

Silver Line Washington Street connects Dudley Square with Downtown Boston. Dudley Station is a major bus transfer point. Most of the bus routes that serve Roxbury and Dorchester either stop or terminate at Dudley Station. The Silver Line is the only route that links Dudley Station to Downtown, which is both a major attraction for retail, office, and entertainment uses and also a major transfer point in the transit system. The Washington Street corridor between Dudley and Downtown was historically the only route connecting the colonial town of Roxbury to the Boston peninsula. The South End district of Boston,

which had been predominantly low-income, began to attract wealthier residents in the 1970s. Even as late as the 1990s, however, Washington Street had many abandoned properties. At the south end, Dudley is a commercial district that has some underutilized properties.

When the elevated Orange Line was removed from Washington Street in 1987, the MBTA agreed to provide high-frequency replacement service. Some residents organized in favor of promoting light rail service on Washington Street. They were bitterly opposed to any replacement service that would be “just a bus.” Thus even before project planning began, the MBTA had difficult customers to please.

Figure 1: New Flyer 40 ft CNG Silver Line Bus Approaching Station



2.0 PROJECT DESCRIPTION

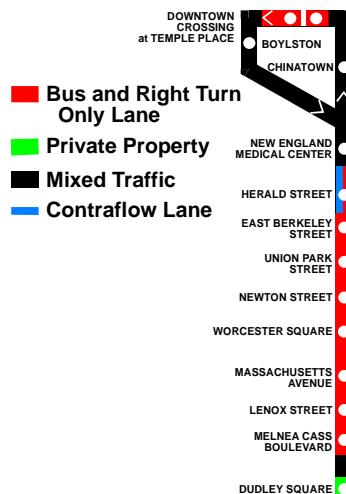
A BRT system is composed of an integrated package of elements that, taken together, create a distinct identity and unique brand. The purpose of this section is to offer a detailed description of the following six major BRT elements as presented in the CBRT report:

- Running ways
- Stations
- Vehicles
- Fare Collection
- Intelligent Transportation Systems (ITS)
- Service and Operations Plan

2.1 RUNNING WAYS

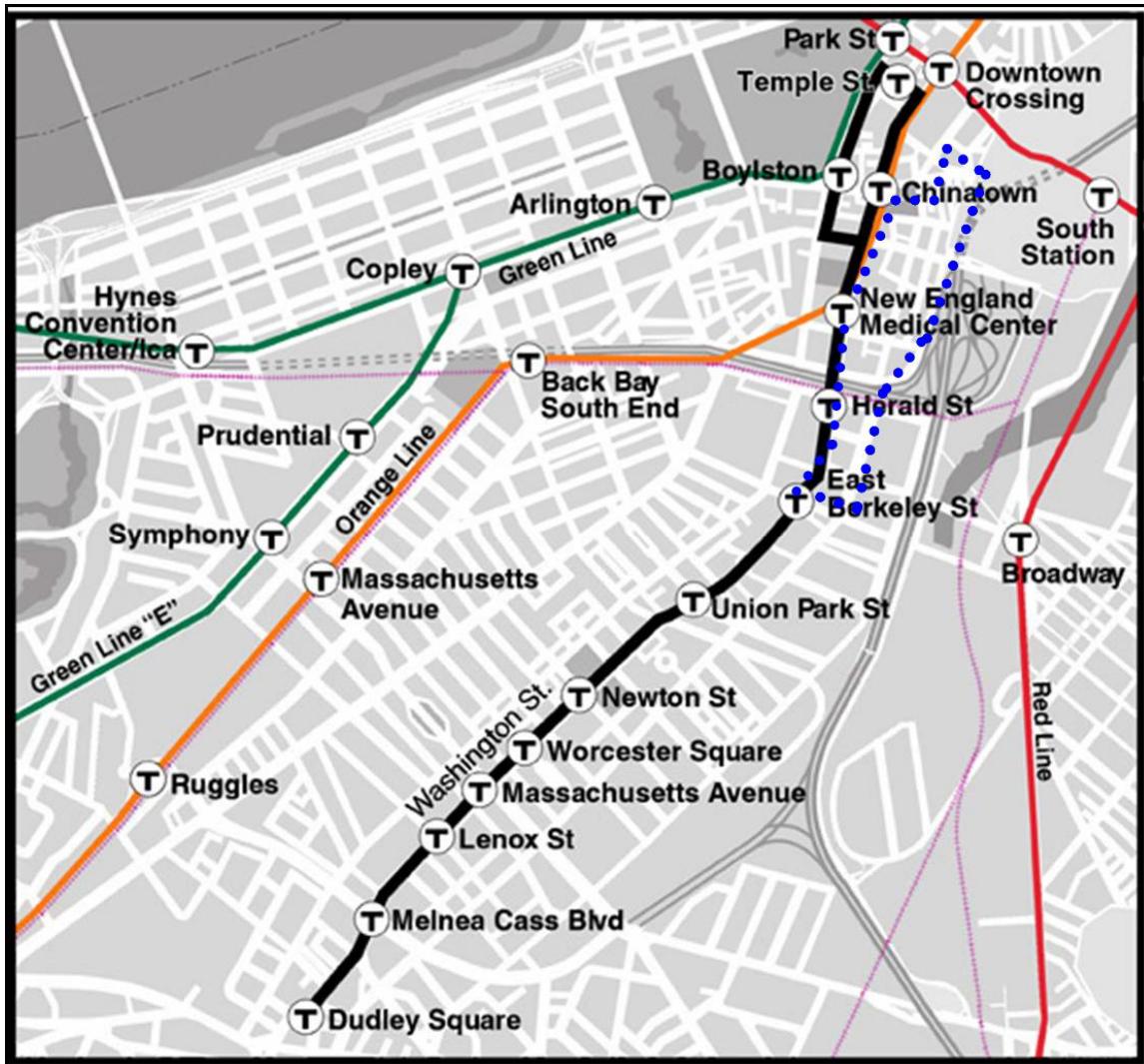
Silver Line Washington Street is a replacement for bus Route 49, which was a temporary replacement for the elevated railway that operated on Washington Street until 1987. The Silver Line operates in a bus-only lane for much of its alignment (Melnea Cass Boulevard to Herald Street, as shown in Figure 2). When approaching intersections where right turns are permitted, the bus lane functions as a right-turn only lane except for buses. Bicycles are also permitted in the bus lane, according to the MBTA, even though the signage, Right Lane Bus Only, seems to require bicyclists to use the general travel lane adjacent to the bus lane. On-street parking is allowed adjacent to the bus lane, except at stations, where the sidewalk extends into the parking lane. There is a three-block section of contraflow lane from Herald Street to Berkeley Street for buses only.² From Melnea Cass Boulevard to Dudley Station, and from Herald Street to Temple Place, the Silver Line operates in mixed traffic.

Figure 2: Silver Line Washington Street Running Ways and Station Stops



² This lane is marked Do Not Enter, MBTA Vehicles Only. The MBTA has stated that bicycles are permitted, but the signage appears to indicate otherwise.

**Figure 3: Silver Line Washington Street Route and Station Stops;
(Former Route 49 is shown in dots)**



Compared to its predecessor, Route 49, the only change in alignment was in the Downtown portion of the route. The former Route 49 is shown in a dotted line in Figure 3; the Silver Line route is shown as a thick line. Compared to Route 49, the inbound Silver Line penetrates further into downtown, providing a convenient transfer (half a block walk) to the Red Line and Orange Line at Downtown Crossing. The Outbound route of the Silver Line stops directly in front of the Green Line station at Boylston Street, another improvement in connections. The most dramatic change, however, was that outbound Route 49 used the Surface Artery and Herald Street all the way to East Berkeley to avoid the one-way section of Washington Street between East Berkeley and Herald. The contraflow lane for those three blocks thus enabled the Silver Line to avoid a major detour. The outbound route of the 49 was neither particularly quick nor in a location, adjacent to the interstate ramp system, where most riders wanted to be.

Washington Street at East Berkeley Street is shown in Figure 4 before installation of the contraflow lane and in Figure 5 after. Note that the west side of the road (on the left-hand side of the picture) was widened and curbside parking was removed to provide room for the contraflow lane. Raised bendable plastic dividers are used to mark the contraflow lane. There is also a with-flow bus lane on the opposite side.

**Figure 4: Washington Street at East Berkeley Street Before Construction
(One-way traffic flow permits inbound service only)**



**Figure 5: Washington Street at East Berkeley Street After Construction
(Outbound bus is operating in contraflow lane obtained by removing parking and moving the curb. Note inbound bus stop on right)**



2.2 STATIONS

On the inbound route there are 11 station stops (not counting the origin) in 2.246 miles, for an average of one stop every 1/5 of a mile. However, the actual spacing varies from as little as a block and a half (Massachusetts Avenue to Worcester Square) to as much as 0.341 miles (Dudley Station to Melnea Cass Boulevard). On the outbound route there are also 11 stations. Because Washington Street is one-way and because of the need for a turn-around loop, the outbound route is 1/4 mile longer. The inbound and outbound stops are generally opposite each other. In the downtown section, the Chinatown (inbound) stop is on Washington Street but the Boylston (outbound) stop is on Tremont Street, which serves as the one-way pair to Washington Street in this area.

Route 49 previously had 20 stops in each direction including its two termini. The plans for Silver Line Washington Street reduced this to 11 stops. Despite considerable community input into the location of the consolidated stops, residents of a Boston Housing Authority senior-citizen project on Washington Street began to complain about the loss of a stop immediately adjacent to their building shortly after the new stop plan became effective in July 2002. The Mayor of Boston asked the MBTA to add a stop at Worcester Square. The Silver Line began serving Worcester Square again in November 2002. To bring the new stop up to the standards of the other stations, the MBTA constructed shelters, kiosks, and related amenities at the additional pair of stops.³

Each station, as shown in Figure 6, includes an architecturally-designed shelter, seating for five, a trash receptacle, a bike rack, and an emergency call button. The stations also have kiosks with the station name and direction, a route map, a system map, a neighborhood map, and a historical marker. The kiosk also has an LED variable message sign and hardware for displaying real-time passenger information and communicating with traffic signal controllers. The sidewalk expands into the parking lane at the station, providing ample room for waiting passengers, street furniture, and pedestrian passage. The Silver Line has its own berth at the terminal at Dudley Square with a route map and Silver Line graphics. The Chinatown and Boylston stops have signs only. The downtown terminus at Temple Place has an enclosed glass bus shelter provided and maintained by Wall USA, which has installed about 250 such shelters in Boston, supported by advertising revenues.

³ However, the inbound stop lacks a shelter as of this writing.

Figure 6: Silver Line station (Union Park)

Prior to the creation of the Silver Line, most of the stops along the route were marked by a sign with the legend, MBTA Bus Stop, No Parking. There was no information about which route(s) served the stop, nor the route destination, nor the schedule. The inbound stop approaching Massachusetts Avenue is shown in Figure 7 prior to construction. The same location after construction is shown in Figure 8. The new sidewalks, bus lane, shelter, kiosk, and passenger information are visible.

**Figure 7: Massachusetts Avenue Inbound Stop Before Construction
(Passenger information is missing)**

Figure 8: Massachusetts Avenue Inbound Stop in 2005
(Note: wider sidewalk, specialty pavers, historic light pole, bench, shelter, information box on sign post, kiosk with route map, and combined bus and right turn lane)



2.3 VEHICLES

To meet the anticipated demand and to provide a completely new vehicle, the Silver Line was designed to use new, low-floor, articulated compressed natural gas (CNG) buses. However, when service began in July 2002, the 60 ft. buses were still on order. Instead, 40 ft. low-floor CNG New Flyer buses were used temporarily. These low floor buses have 39 seats in a configuration with two seats, aisle, and two seats (2 + 2). Bus Route 49 used older 40 foot RTS high-floor diesel buses which had 40 seats in a 1 + 2 configuration, thus providing more circulation space. (Low-floor buses have less room for seats due to the intrusion of the wheel wells in the passenger compartment.) Beginning in July 2003, 60 ft. articulated low-floor CNG Neoplan buses replaced the 40 ft. CNG buses.⁴ The Neoplan buses have three doors and 57 seats in a 2 + 2 seating configuration. They are 102 inches wide. Seventeen of these were purchased for designated use on the Silver Line in special Silver Line livery (see Figure 9). The purchase price per vehicle was approximately \$770,000, including procurement costs.

Figure 9: 60 ft. Articulated CNG Neoplan Bus in Silver Line Livery



The MBTA created a new facility, the Southampton Street Garage, to maintain and store the new CNG vehicles. The new depot is home to the Silver Line fleet (both Washington Street and Waterfront) and 27 additional 60 ft. Neoplan CNG buses in standard livery, used on bus route 39.

⁴ *The 40 ft. buses were still used as the 60 ft. buses were being delivered over some months. Because of unexpected noise from the 60 ft. buses, the 40 ft. buses were used in the evenings while the manufacturer was developing a solution to reduce excess bus noise from the new buses.*

2.4 FARE COLLECTION

No changes in the fare collection technology were implemented with Silver Line deployment. Like other MBTA buses, the Silver Line, until the AFC pilot program began, accepted cash (coins only, no change provided), magnetic strip cards, flash passes, and paper transfers. However the fare structure was modified with the launch of the Silver Line. In general, no reduced-price transfers are permitted from MBTA bus to MBTA rail services; a full additional fare is required. However, because bus Route 49 was a replacement for the relocated Orange Line, a free transfer was permitted at New England Medical Center inbound and the Surface Artery outbound. With the opening of the Silver Line in 2002, the free transfer policy was maintained at NEMC, which directly served outbound as well as inbound, and was extended to Downtown Crossing (Temple Place) and Boylston Stations. Transfers from rail to bus, and bus to rail, were also made available at these three stations. With the introduction of articulated buses, the pay on boarding policy was not changed, even though three doors for boarding are potentially available. One exception is that boarding is permitted from the middle door for pass holders when an inspector is present to check passes at Dudley or Temple Place.

On January 31, 2005, an automatic fare collection (AFC) pilot program began in the MBTA system with the use of the Silver Line as a test case. AFC will later be extended to all bus and rail services. The new equipment reads proximity cards, magnetic strip cards, bills and coins; an example is shown in Figure 10. All transactions are checked for validity. Complete information is read from magnetic strip cards, compared to the basic checking of the old fareboxes. Soon after installation of the AFC fareboxes, it became apparent that boarding delays increased substantially. Some of the delay was the result of the additional time needed to check individual coins and bills. Also, if coins were dropped too quickly in succession, the system produced an error. These problems were compounded by the limited availability of proximity cards, which were only distributed to 300 riders as part of the demonstration. The MBTA was planning to install redesigned fareboxes in September 2005 that have modifications designed to reduce fare payment delay.

Figure 10: Automatic Farebox Installed on the Silver Line, February 2005



2.5 INTELLIGENT TRANSPORTATION SYSTEMS

The Silver Line Washington Street project was designed to incorporate several Intelligent Transportation Systems (ITS) components, including Automatic Vehicle Location (AVL) and Computer-Assisted Dispatching (CAD); Public Address and Variable Messaging Signs (PA/VMS); Traffic Signal Priority (TSP); and real-time passenger information. The vendor for all of these systems is Siemens. The Silver Line also is equipped with Automatic Vehicle Monitoring (AVM), which uses a combination of Siemens and Maximus software and equipment.

Automatic Vehicle Location (AVL) and Computer Aided Dispatching (CAD)

To assist with scheduling and planning, all Silver Line vehicles are equipped with a GPS device and a vehicle unit, an on-board computer. The GPS device obtains the bus position and communicates it to the vehicle unit, which periodically sends its location to the Bus Control Center. The vehicle run information (vehicle times at different locations) is transmitted from the vehicle unit and is used to produce reports of travel time that can be used for planning and scheduling. The Computer Aided Dispatching part of the system consists of route management software at the Bus Control Center that displays real-time vehicle locations along a route map. The system is also used to communicate with vehicle operators. The Hastus scheduling software provides direct updates of quarterly schedule information to both the CAD/AVL and PA/VMS systems. The AVL system does not include Automatic Passenger Counters (APCs); therefore the data from the system does not include ridership estimates.

Public Address and Variable Messaging Signs (PA/VMS)

ITS systems can provide improved passenger information. The public address (PA) system broadcasts pre-recorded stop announcements both inside the vehicle in advance of a stop and outside the vehicle to waiting passengers. The information is also displayed on an LED variable message sign (VMS) inside the vehicle. The stop locations are known through the GPS system. This decreases passenger anxiety and improves customer satisfaction. These systems were also retrofitted to some older MBTA buses and are included with all new MBTA bus purchases.

Traffic Signal Priority (TSP)

Traffic signal priority is designed to reduce traffic signal delay to transit vehicles. The logic chosen for the Silver Line is to request priority only for those vehicles that are behind schedule. Although TSP was a component of the system from the initial planning, the system is not operational three years after the project began. One reason for this delay is the numerous parties involved. The signal subcontractor, reporting to the MBTA's primary contractor, is responsible for hardware installation. Responsibility for programming and operating the signals lies with the Boston Transportation Department (BTD). The system software provider is Siemens. Signal priority is planned for the major signalized intersections with far-side bus stops: Melnea Cass Boulevard, Massachusetts Avenue (southbound only), East Berkeley Street and Herald Street.

Also adding to the delay is the complexity of the system operating scheme. At specific pre-determined points approaching an intersection, the bus on-board computer sends its location to the MBTA Bus Control Center. The central computer then checks the bus number and the schedule to determine if it is behind schedule. If so, it sends a signal to the hardware contained in the kiosk located at the bus stop on the far side of the intersection. The kiosk, via hardwire, sends a "contact closure" signal to the intersection signal controller, which in turn passes the signal to the BTD central computer system at City Hall. The BTD computer then decides to grant priority (hold the green signal longer or display it sooner) only if priority has not been granted on the previous signal cycle and if the waiting queue on the side street is less than a predetermined length. The complete sequence from initial location announcement to granting priority is designed to take just a few seconds. The MBTA has provided BTD with funds to create a system to track and report the frequency that priority is granted. If the Silver Line program is successful, signal priority could be deployed elsewhere in the City of Boston. One possibility to reduce the complexity of the system would be to provide a direct, secure link from the MBTA central computer to the BTD central computer. This would eliminate the need for special wayside hardware such as that contained in the kiosks and would cut several steps from the process.

Real-Time Passenger Information

The kiosks also contain an LED variable message sign (VMS) and the ability to communicate with the MBTA central computer. There are also VMS displays at the termini, Dudley Station and Temple Place. Dispatchers can display service updates, emergency messages, or notices of a service disruption in real time. The system also includes bus countdown software that displays the arrival time of the next vehicle. The countdown display was briefly operational, but the MBTA was not satisfied with the quality of the predicted arrival times. Testing of the system with new software is to resume in September 2005. Currently the VMS displays headway information based on the schedule.

Automatic Vehicle Monitoring (AVM)

The AVM system provides information about the status of vehicle and engine conditions, which can be recorded and monitored remotely. For the Silver Line vehicles, the conditions reported are as follows: Door open, Stop request, Retarder off, Low air, Low fuel, Check engine, Stop engine, Check transmission, A/C Fail, ABS warning, Hinge fault, Fire/Methane detection, Low Coolant, Low Oil Pressure, and Hot Engine. The system was being tested as of July 2005. The MBTA is also testing a new farebox interface for common system log in and farebox monitoring. This would add such measures as "low ticket stock" and "farebox vandalism detected" to the AVM system.

2.6 SERVICE AND OPERATIONS PLANS

The Silver Line Washington Street was an upgrade to, and replacement for, bus route 49. It provides a similar function of basic local access, rather than being an express or limited-stop route. Because it is considered to be part of the "rapid transit" system, it meets the rapid transit service minimum standards. These are:

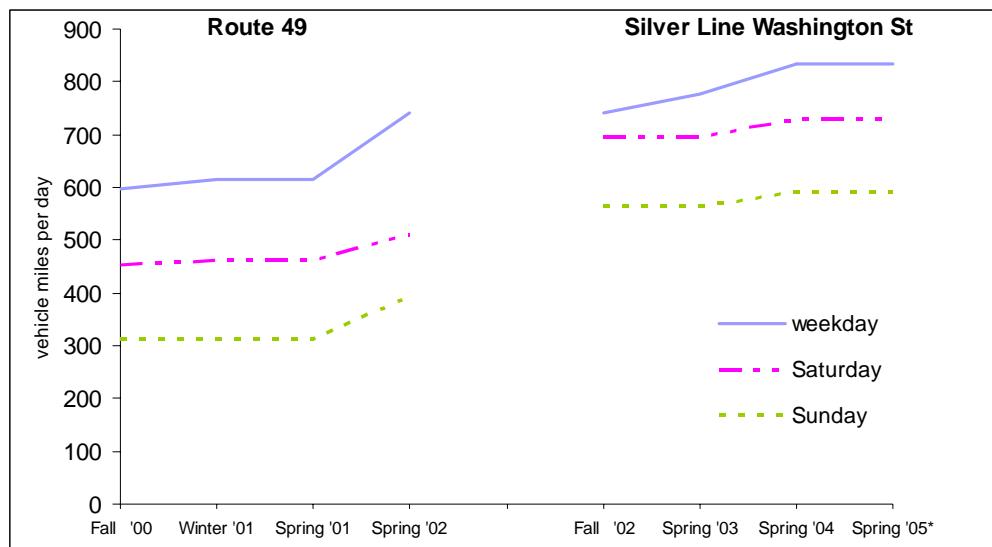
Service Frequency: headways of 10 minutes in the peak and 15 minutes in the off peak;

Span of Service: 6 am to midnight Monday to Saturday, 7 am to midnight Sundays. In fact, Silver Line service operates for a longer span of service and more frequently than these minimums.

Service is scheduled based on individual trip departure and arrival times, even though these departure times are not generally advertised to the public, given the high frequency of service. Headway-based scheduling was not considered for the service and is not used elsewhere in the MBTA system. Typically, schedules are changed quarterly based on seasonal variations and on updated running time data, including, in the case of the Silver Line, AVL-generated information.

Trend in Vehicle Miles

As shown in Figure 11, about 600 daily vehicle miles of service were offered on weekdays on Route 49 in Fall 2000. This figure increased slightly in subsequent quarters, and then increased considerably with the Winter 2001 quarter, which coincided with the opening of the contraflow lane and the elimination of the detour. Following the official Silver Line launch of July 2002, the amount of service provided increased further, particularly on weekends. Despite the introduction of higher-capacity articulated buses in July 2003, the number of trips increased further, in response to heavy demand. Between Fall 2000 and Spring 2005, vehicle miles of service increased 40% on weekdays, 61% on Saturdays, and 90% on Sundays. The larger increase on weekends reflects the fact that most MBTA bus routes offer a much lower frequency of service on weekends than during the week. The frequency increased substantially on weekends in order to meet the minimum headway policies for "rapid transit" quality service.

Figure 11: Vehicle Miles of Service Per Day, Route 49 and Silver Line

2.7 SYSTEM COSTS

The Silver Line transit project was planned jointly with the Washington Street reconstruction project. The City of Boston was centrally involved in planning the joint transit and road reconstruction project. The Massachusetts Highway Department reimbursed the MBTA for the road construction portion of the budget.

The major costs of the Silver Line project were vehicle procurement and roadway and station construction. Figure 12 provides a capital cost summary of Silver Line Washington by project element. The total project capital cost was \$27 million, or about \$11 million per alignment mile (not directional route mile). About half this cost was for vehicles and half for infrastructure, and only \$750,000 for the CAD/AVL contract. The custom-designed bus shelters cost \$170,000 each, or \$2.55 M for 15 shelters (Robin Washington, *The Boston Herald*, "No Silver Lining to T Bus Shelters," June 2, 2003).

Figure 12: Project Capital Budget, as of July, 2005

| Project Element | cost |
|------------------------------------------------------|--------------|
| 17 60-foot articulated low floor CNG buses (Neoplan) | \$10,880,000 |
| Procurement and other vehicle soft costs | \$2,220,000 |
| Kiosks, portion of roadway work | \$10,890,000 |
| Shelters | \$2,550,000 |
| CAD-AVL system | \$750,000 |
| Total | \$27,290,000 |

Note: The contract also included \$19.23 million for road construction not attributable to the Silver Line that was reimbursed by the Massachusetts Highway Department.

3.0 PLANNING, DESIGN AND IMPLEMENTATION

The Silver Line Washington Street project has a long history. Protests against the planned location of the Southwest Expressway (Interstate 95) through Boston led to the decision in 1972 to cancel the highway project and, as a substitute, relocate the elevated Orange Line from Washington Street to the corridor that would have accommodated the expressway. In the 2½ mile stretch of Washington Street between Dudley Square and Downtown, the new Orange Line would be four long blocks distant. Therefore the MBTA agreed to provide interim high-frequency bus service in that corridor after the elevated was removed, and then to start construction of permanent "replacement" service. The replacement service study project was initiated in 1978. In 1987 the Federal Transit Administration (then UMTA) rejected New Starts funding for the proposed light rail alternative, which it deemed not cost-effective, and too close to the relocated Orange Line.

Also in 1987, the new Orange Line was completed and opened for service, and the elevated was demolished. The interim replacement bus service from Dudley to Downtown, Route 49, featured frequent service compared to many other MBTA buses and a free transfer to the Orange Line where the routes merged. The service stopped just short of Downtown Crossing, a major access point for the MBTA's other lines.

In 1989, the MBTA selected electric trolleybus (or "trackless trolley") as the preferred alternative for permanent replacement service, to be funded with state funds only. The decision was contested by the Washington Street Corridor Coalition (WSCC), a group advocating light rail on Washington Street. The MBTA's arguments against light rail concerned the operational difficulties of adding more trains into the central subway. The additional cost of light rail, given the lack of Federal funding, was another factor. The major concern of abutters was the potential for loss of on-street parking due to the space requirements of a median reservation for light rail. Further, the demand in the corridor would only justify 12 minute headways in the peak period if articulated light rail vehicles were used, but 4 minute headways if trolleybus were chosen. Thus even though the light rail alternative would have a shorter running time for those going to Downtown, average trip times, including waiting, would be similar.

The MBTA resubmitted its proposal to FTA, asking for funding for light rail. In 1992, FTA again found light rail to be cost-ineffective. The MBTA commissioned a further study of the project, including a detailed look at the alternative light rail alignment proposals. That study also concluded that trolleybus was the best option.⁵ By 1996, nearly ten years had passed since the elevated had come down, and plans to repave Washington Street were still not approved. With the economy in good shape, the many underused properties in the area were under consideration for development. Property owners were anxious to improve the look of the street. The Boston Society of Architects held design charettes about Washington Street. The MBTA held a series of public hearings in October, 1996 and made the following decisions:

⁵ Fay, Spofford & Thorndike. 1995. Washington Street Transit Replacement Services: A *Technical Review of Proposed Trackless Trolley and Light Rail Options*. Boston, MA. April 7, 1995.

- In wider sections of Washington Street, the service would run in a bus lane next to a permanent parking lane.
- Because of neighborhood opposition to the visual impacts of overhead wires, particularly in the downtown section of the route, alternative fuel (non-diesel) buses would be used instead of electric trolleybus.
- The new service would be called the Silver Line, and would eventually link to the South Boston Piers project, a bus tunnel from South Station to South Boston.

In April, 1997, following a request from the City of Boston and Boston-area state legislators, the MBTA further agreed that:

- The Silver Line will be “given the status of a rapid transit service”— the route would be shown on the system map and would offer free transfers to other rapid transit lines.
- A design committee including many community representatives would consider details of station locations, lanes, urban design, and the downtown turn-around loop.
- Construction would begin in 1999 and service the following year.
- A future underground connection to the rapid transit system would be planned as a second phase.

The design committee reported in May 1998. The report proposed new station locations, shelter designs, and streetscape elements and left the decision about the downtown loop to future study. The MBTA submitted an Environmental Notification Form for the Silver Line project to the Massachusetts Department of Environmental Protection in July 1998. In 1999, the Silver Line was included as one of the Federal Transit Administration’s BRT Demonstration Projects. The project design drawings were completed in 2001 and construction began that year. Route 49 was rerouted on the new Silver Line route using the contraflow lane in December 2001. The official opening of the Silver Line was July 2002, including deployment of new buses. Road construction was not completed until later that year, and a few final items, such as signal priority connections, were still being completed in 2005.

3.1 PROJECT DEVELOPMENT SCHEDULE

The following is a schedule of developments related to Silver Line Washington Street:

- Project planning (1997-1999)
- Engineering and design (2000-2001)
- Start of construction (2001)
- Contraflow Lane opens and Route 49 re-routed (December 29, 2001)
- Start of Silver Line Service (July 20, 2002)
- Worcester Square stop added to the route (November 2002)
- Construction of Worcester Square station complete (2003)
- Articulated vehicles begin to enter service (July 2003)
- Articulated vehicles complete noise abatement retrofit (Summer 2004)
- Automatic Fare Collection equipment installed (January 31, 2005)
- Schedule revised to incorporate layovers at Temple Place; no-parking barrels installed to permit traffic to pass stopped buses (June 25, 2005)

3.2 STATION PLANNING

The concept of curbside bus lanes adjacent to a parking lane with “bulb outs” at stations was approved in 1996. The specific station planning was largely the work of a design committee appointed by the City of Boston. The committee started with the premise that there would be fewer stops—more like the spacing of the MBTA’s streetcar service than its bus service. Prior to the Silver Line, almost every other block was a bus stop. The design committee was able to take a “zero-based” approach to station planning: rather than eliminating old stops, it would start from zero and decide where to place the “stations.” There was little resistance to stop elimination in the planning process. When the service began making only the new stops, the residents of one housing project successfully fought to have “their” stop restored, even though the nearest stop was two short blocks away. Despite this one change, the project succeeded in reducing the number of stops from 20 to 12 with little opposition—and significant approval, considering ridership statistics. Reducing the number of stops also facilitated providing more amenities at each stop. Far side stops were preferred in order to facilitate traffic signal priority. However, several of the stops were near side in order to accommodate other concerns, such as abutters’ preferences.

A separate process was used to determine the downtown loop. Consultants proposed two alternative routes and drove them to record test travel times. The selected route was the overwhelming favorite. However, no permanent stations were designed for the downtown loop (Chinatown, Temple Place, and Boylston stops). A Wall USA shelter and an LED variable message sign controlled by dispatch were added to the Temple Place stop, but the other two downtown stops are marked currently only by signs.

3.3 INSTITUTIONAL SETTING

The Massachusetts Bay Transportation Authority (MBTA) was created in 1964 as the successor to the Metropolitan Transportation Authority (MTA).⁶ This change expanded the transit service region from 14 cities and towns clustered around Boston to 78 cities and towns encompassing a large part of Eastern Massachusetts. More recently, the region has been expanded to 175 member communities. The MBTA has a Board appointed by the Governor. The cities and towns in the MBTA region are represented by the MBTA Advisory Board, which has the power to review the MBTA budget but has no decision-making authority.

The MBTA inherited a system that included streetcars (trolleys), motor buses, electric trolley buses (trackless trolleys), and heavy rail running in both underground and elevated rights of way. In August, 1965, the MBTA created a color scheme for its remaining rail routes. The heavy rail lines were labeled Blue, Red, and Orange. The streetcar system was designated the Green Line, and its five branches were assigned the letters A through E. The numerous bus routes were not included in this color scheme and were left off the schematic system map. The MBTA subsequently acquired the remaining private transit bus operators in the region. In the 1970s and 1980s, the MBTA extended the Red and Orange heavy rail lines and took over regional railroad passenger operations (commuter rail). The commuter rail system was expanded in the 1990s. The Silver Line represents the first addition of a colored line to the core color system since 1965. It is also the first time that a rubber-tired line was given "rapid transit" status.

The City of Boston was also a major stakeholder in the process. The City owns the streets, sidewalks, and traffic signals. The city's Transportation Department (BTD) collaborated with the MBTA in jointly planning both the transit-specific and other aspects of the roadway design. The Massachusetts Highway Department funded the roadway portion of the project and reviewed the designs to insure their consistency with department standards.

⁶ *The MTA was a public entity created to take over the operations of the Boston Elevated Railway.*

3.4 LESSONS LEARNED

This section describes some of the lessons learned in Silver Line Washington Street, the MBTA's first BRT deployment.

New vehicles

The deployment of new vehicles was essential to conveying the image of a new type of service. However, the buses chosen were firsts for the MBTA in several ways: the first low floor, the first CNG, and the first articulated. Despite this, there were relatively few problems. The first problem was that the preferred vehicles took longer than anticipated to be delivered, in part because they were the first low-floor articulated CNG buses to be used in the United States. As a new model, the Neoplan articulated bus was required to be tested at the Altoona Bus Research and Testing Center. This process took 18 months and was completed in January, 2003. The low-floor vehicles meant a small reduction in the number of seats and perhaps a greater reduction in circulation space. This problem was solved by the switch to articulated vehicles with extra seating and standing capacity. However, those vehicles soon developed another problem: a low, loud vibration, especially on acceleration.⁷ The MBTA received numerous complaints about the problem and it was reported in the press. As soon as the complaints were received, the MBTA began working with the bus manufacturer to resolve the problem. Four separate modifications were tested before an acceptable fix was found. Retrofitting the whole fleet of articulated buses took more time. In the meantime, the MBTA deployed the lower-noise 40 ft. buses after 9 pm. In all, the process of fixing the excess noise took about a year. Excess noise detracts from customer and public perception of the image of the system. Thus prompt attention to the problem, as occurred in this case, is important.

Intelligent Transportation Systems

The complexity of ITS requires that potential delays be incorporated in the planning of new services. Almost all of the ITS proved more complex to deploy than originally anticipated. The CAD/AVL system had few problems, and has been a key component in maintaining reliable service. On the other hand, real-time passenger information has not been consistently operational, but planned modifications in the software and installation of dead reckoning will soon improve the real-time output. Signal priority has not been implemented more than three years after project opening; it was delayed due to both construction and software issues.

Project Planning

This project was stalled for many years, in part because of the controversy over whether to use light rail or bus. FTA's denial of New Starts funding for the original light rail proposal supported the financial case for bus instead of light rail. The pressing need to repave the roadway helped to create a consensus to take action. The consensus was achieved in part

⁷ It was determined that the articulated bus's 6 cylinder engine idling at 700 rpm produces a frequency of about 35 Hz, which creates vibrations in buildings and is bothersome to people. The 40 foot buses make a higher-frequency sound at idle due to their 4 cylinder engine. Changing the idle speed would have required re-certifying engine emissions with US EPA, a long and difficult process. Thus the solution was to develop a better muffler.

because of a prior decision to create a bus route more like MBTA light rail than MBTA bus, and also because the system was designed so that it could be converted to light rail. The mandate to create a bus that was not “just a bus” enabled the project planners to provide a level of attention to vehicles, running ways, passenger information, and route performance that would have been impossible had the project been designed merely to make some improvements to an existing bus route.

4.0 EVALUATION OF SYSTEM PERFORMANCE

The purpose of this section is to evaluate Silver Line system performance based on the core elements that compose BRT system performance: 1) travel time, 2) reliability, 3) image and identity, 4) passenger safety and security, and 5) system capacity.

4.1 TRAVEL TIME

Total *passenger* travel time includes getting to and from the transit stop (access time), waiting time, and time on board the vehicle (running time).⁷ If a trip requires a transfer to another vehicle, the total trip time will include access, waiting, and running time for the second (or subsequent) segment(s).

Running time. Running time includes time in motion, acceleration and deceleration at stops, delay at traffic signals, and delay while loading and unloading passengers (*dwell time*). Compared to bus 49, Silver Line Washington Street is hypothesized to have a shorter running time because of the reduction in the number of stops and a slightly shorter outbound route. The exclusive bus lanes may also reduce delay due to traffic congestion. The change in the outbound route may have reduced congestion delay, particularly in the afternoon peak when backups on the expressway ramps created delay on the Surface Artery, a road no longer on the route.⁸ However, the slightly extended route to Temple Place also experiences significant congestion at some times of the day.

Traffic signal delay. As of summer 2005, the traffic signal priority system planned for four intersections was still being tested. However, the combination bus and right-turn lanes at most intersections along the South End portion of the route may contribute to reduced signal delay. At peak periods, Silver Line buses in the bus/right-turn lane bypass queues of vehicles waiting to proceed straight. Right turning vehicles generally do not block the bus lane, in part because turn on red is permitted at most intersections along the route.

Dwell time. All other factors being equal, dwell time increases with more boardings and alightings, and with additional crowding on the vehicle. The shift to low-floor vehicles would tend to reduce boarding and alighting time per passenger by reducing the number of steps. (Door width can also affect boarding and alighting times, but it did not change with the new vehicles.) The amount of circulation room within the vehicle affects dwell time. The older, high-floor buses had two seats on one side but only one on the other, leaving a wide aisle. The new low-floor buses have two seats on either side of a narrower aisle. This configuration was chosen to reduce the loss of seats due to the location of the wheel wells inside the passenger area in low-floor vehicles. Boarding delay is greater than alighting delay because passengers must pay and use only the front door when boardings.⁹

⁷ For low-frequency service, passengers often arrive to meet the published schedule time, reducing their waiting time but possibly incurring schedule delay. However, the Silver Line is a high-frequency service and only the frequency of service, not the trip departure time, is advertised.

⁸ The completion of the Central Artery project in 2004-2005 may have reduced or eliminated some of these delays.

⁹ At the two terminals, MBTA inspectors permit pass-holding customers to board from one of the rear doors, when many customers are waiting to board.

Running time variability. Variability in running time can increase the number of very crowded trips, thus increasing dwell time, and thereby lengthening mean running time. The reduction in the number of stops would tend to reduce variability of running time because there would be less variation in the number of accelerations and decelerations from trip to trip, since having fewer stops increases the likelihood that at least one person is boarding or alighting at any stop. The avoidance of areas with periodic, large congestion delays (such as the former bus route 49's return trip along the Surface Artery) would also tend to reduce variability, as would a targeted reduction in traffic signal delay. The Automatic Vehicle Location system may contribute to a reduction in trip time variability in two ways. First, the running time reports enabled by the system can be used to schedule sufficient running and recovery time to enable more trips to start on schedule. Second, the Computer Assisted Dispatching (CAD) component of the system enables dispatchers to take measures such as holding or expressing buses in order to keep them on schedule.

**Figure 13: Running Time, Route 49 Compared to Silver Line, Weekdays
(Calculated from CTPS ridecheck data)**

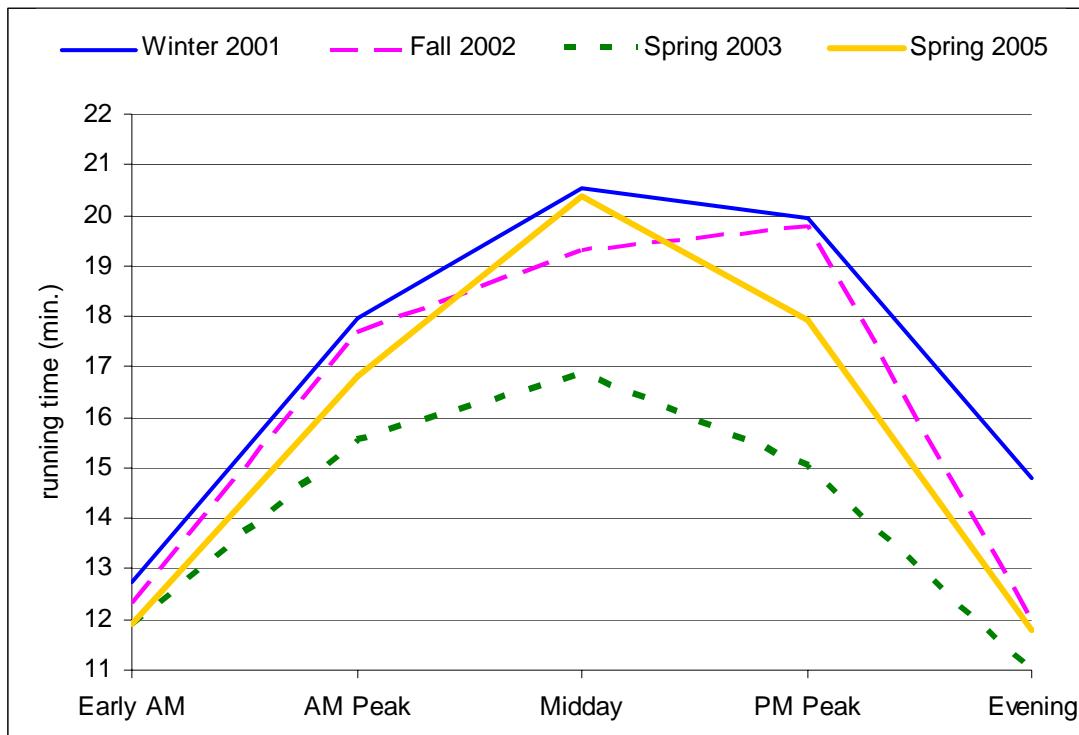
| Service Type & Date | Measure | Inbound | | | | | Outbound | | | | |
|---------------------------------------------|---------|----------|---------|--------|---------|---------|----------|---------|--------|---------|---------|
| | | Early AM | AM Peak | Midday | PM Peak | Evening | Early AM | AM Peak | Midday | PM Peak | Evening |
| Rt. 49 | sched. | 15.0 | 16.9 | 17.3 | 18.0 | 15.3 | 16.1 | 17.1 | 19.9 | 19.6 | 15.3 |
| Winter 2001 | mean | 12.8 | 18.0 | 20.5 | 20.0 | 14.8 | 11.8 | 15.9 | 20.5 | 19.5 | 13.8 |
| | s.d.* | 1.5 | 3.2 | 3.0 | 3.0 | 2.9 | 2.3 | 1.8 | 4.6 | 3.9 | 2.6 |
| Silver Line | sched. | 12.0 | 16.7 | 17.0 | 16.6 | 12.5 | 14.1 | 16.2 | 18.6 | 18.8 | 14.0 |
| 40 ft. buses | mean | 12.3 | 17.7 | 19.3 | 19.8 | 11.9 | 12.8 | 14.9 | 17.7 | 17.8 | 13.0 |
| Fall 2002 | s.d. | 2.1 | 4.2 | 3.3 | 4.6 | 1.7 | 2.7 | 1.5 | 4.3 | 3.0 | 2.2 |
| Silver Line | sched. | 12.0 | 16.7 | 17.0 | 16.6 | 12.5 | 12.0 | 16.7 | 17.0 | 16.6 | 12.5 |
| 40 ft. buses | mean | 11.9 | 15.5 | 16.9 | 15.0 | 11.0 | 11.9 | 15.5 | 16.9 | 15.0 | 11.0 |
| Spring 2003 | s.d. | 1.6 | 2.6 | 2.5 | 2.2 | 1.9 | 2.1 | 1.7 | 2.9 | 2.4 | 2.1 |
| Silver Line | sched. | 12.0 | 16.7 | 17.0 | 16.6 | 12.5 | 14.1 | 16.1 | 18.7 | 18.9 | 14.0 |
| 60 ft. buses** | mean | 11.9 | 16.8 | 20.4 | 17.9 | 11.8 | 13.1 | 15.2 | 18.7 | 19.2 | 13.5 |
| Spring 2005 | s.d. | 2.0 | 3.3 | 3.4 | 3.7 | 3.3 | 2.5 | 2.0 | 3.0 | 3.1 | 3.0 |
| % change, Spring 2003 vs. Winter 2001 | sched. | -20% | -1% | -2% | -8% | -18% | -26% | -2% | -14% | -15% | -18% |
| | mean | -7% | -13% | -18% | -25% | -26% | 1% | -3% | -18% | -23% | -20% |
| | s.d. | 7% | -18% | -16% | -27% | -34% | -11% | -4% | -38% | -39% | -20% |
| % change, Spring 2005 vs. Spring 2003 | sched. | 0% | 0% | 0% | 0% | 0% | 18% | -4% | 10% | 14% | 12% |
| | mean | 0% | 8% | 21% | 19% | 7% | 10% | -2% | 11% | 28% | 23% |
| | s.d. | 27% | 27% | 34% | 69% | 68% | 19% | 14% | 4% | 33% | 45% |

Notes: *Standard deviation. **The Automatic Fare Collection pilot program was operating at this time.

Measures of running time were available from observations recorded by ride checkers employed by the Central Transportation Planning Staff (CTPS), a state agency, under contract to the MBTA. These checks are the only data available for bus route 49, that is, representing the "before" condition. Checkers are assigned to ride each trip of the day and record boardings and alightings by stop as well as total travel time. Dwell time is not recorded, nor is travel time to any intermediate time point. Not all trips in a single day are recorded. Therefore the "Trip Summary" data provided by CTPS represents a composite day consisting of sequential trip departures that may have been recorded over a series of weeks or months, although all within the same quarterly schedule period.

Bus route 49 was checked on Saturdays and Sundays in Fall 2000, and on weekdays in Winter 2001. The first check of the Silver Line Washington Street took place in Fall 2002; the next check was the following Spring of 2003. Each of these checks recorded both weekday and weekend trips. During both of these checks, only 40-foot buses were in operation. The most recent check occurred in Spring 2005, on weekdays only. This was the first check since 60-ft articulated buses were deployed on the Silver Line. However, it also coincided with a pilot program to test new Automatic Fare Collection fareboxes.

**Figure 14: Inbound Mean Running Time By Time Period
(Various CTPS Ridechecks, Route 49 and Silver Line Washington Street)**

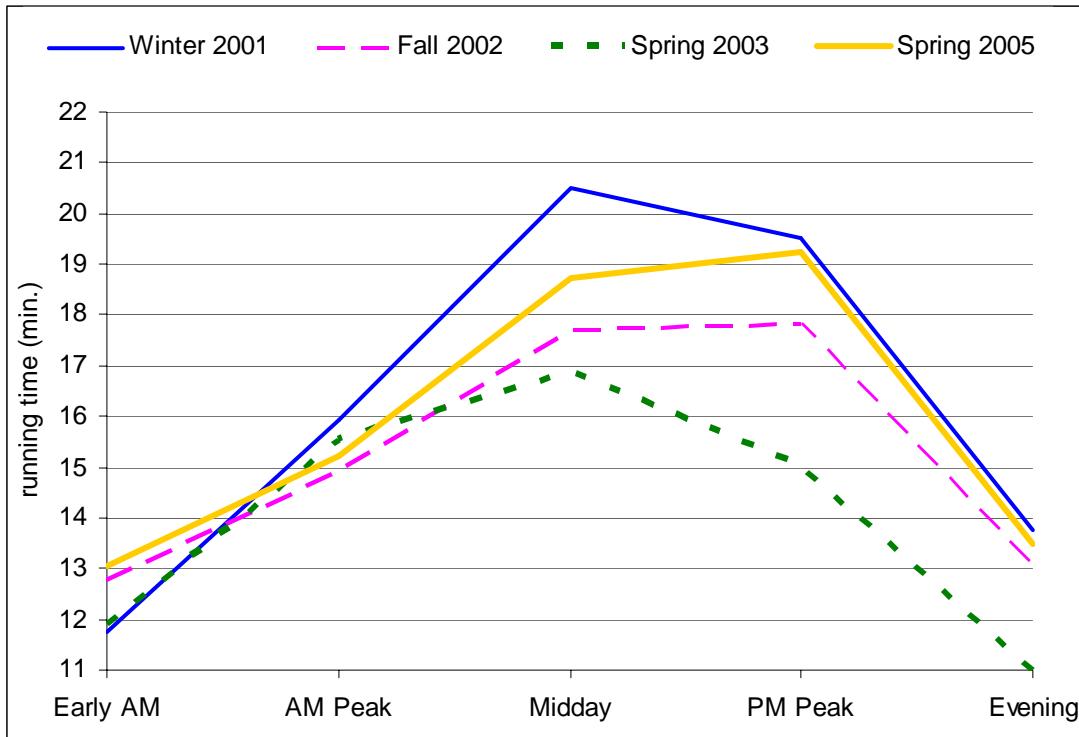


A summary of weekday ridecheck data for each of these periods is shown in Figure 13. Mean actual running times are graphed in Figure 14 (inbound) and Figure 15 (outbound). The first ridecheck of Silver Line service in Fall 2002 showed only modest running time savings compared to the ridecheck of route 49. However, by Spring 2003, the Silver Line Washington Street was showing reductions in mean running time as high as 25%, especially in the midday and PM peak periods.¹⁰ The standard deviation of running time decreased even more, signaling a reduction in the variability of service. This reduction in variability, which may be due to the increasing use of real-time bus management enabled by the CAD/AVL system, may be the reason for the decrease in mean running time, since less bunching reduces mean running time in addition to improving reliability.

¹⁰ During early mornings and late evenings, there are few customers and little traffic congestion, resulting in fast travel times both before and after project implementation.

Scheduled running time decreased compared to route 49, but not as much as actual running time. As a result, in the Spring 2003 survey, actual mean running time was less than scheduled in each period, for the first time. This improvement makes it much more likely that each trip has sufficient recovery time, which is set at about 20% of scheduled trip time.

**Figure 15: Outbound Mean Running Time by Time Period
(Various CTPS Ridechecks, Route 49 and Silver Line Washington Street)**



The ridecheck results from Spring 2005 show a movement in the opposite direction, however. Mean running time increased by 20% or more in some periods. Even more tellingly, the variability of running time (as measured by its standard deviation) increased even more. The explanation for the lengthening of travel time is the deployment of the pilot AFC system. MBTA staff and riders noticed a sharp increase in boarding delay after deployment. The new smart cards were not yet widely available. Moreover, the farebox would fail when too many coins were placed in simultaneously. The MBTA is working with the system manufacturer to reduce or eliminate these problems. However, the increased travel time is evident in the data. The increased boarding delay meant that many trips had insufficient recovery time. This mismatch between schedule and operating conditions meant that dispatchers were struggling to adjust every trip, rather than the occasional late or early trip. The increase in variability is evident in the data.

Dwell Time

Unfortunately, no direct measures of dwell time are available from the AVL system. The Siemens CAD/AVL system is not equipped to record doors opening and closing.¹¹ However, consultants for another MBTA project, the Urban Ring, studied dwell time of 40 ft. low-floor Silver Line buses in 2003. They found that the average dwell time was 24 seconds per stop. Inbound (peak direction) dwell times averaged 29 seconds and the average outbound (off-peak direction) averaged 11 seconds, reflecting the different levels of activity in each direction. The number of passengers boarding was not reported.¹² By comparison, Las Vegas MAX service has mean dwell times of 8 seconds per stop in the AM peak in the peak direction and only 5 seconds in the off-peak direction.¹³ The main explanation for this difference is MAX's proof-of-payment system, which requires fare pre-payment and permits all-door boarding. A local Las Vegas bus route in the same corridor without proof-of-payment showed mean AM peak dwell times of 32 seconds per stop in the peak direction and 24 seconds in the off-peak direction.

The Spring 2005 ridecheck results show that dwell time can have a profound effect on running time and reliability. Almost all the travel time savings from other BRT features were wiped out by the increased boarding delay. The MBTA is already taking measures to eliminate the problems that became apparent in the pilot AFC deployment. However, the inadvertently-created fare payment delay suggests that efforts to further reduce delay in boarding, such as the use of a Proof of Payment fare collection system, might reduce travel time below even the level measured in 2003.

Impact of Boarding Delay on Travel Time

The comparisons of running time presented above do not provide a complete picture of the impact of BRT features on improving running time. Additional ridership slows service, and the number of boardings almost doubled compared to the "before" service. More bus trips accounts for some of the additional ridership. However, the number of riders per trip increased substantially. Thus a more careful comparison of running time should control for the greater number of boardings. This can be accomplished by estimating the statistical relationship between boardings per trip and trip running time. This was done by regressing running time (the dependent variable) against boardings per trips.

Road congestion also affects trip running time, and congestion is positively correlated with boardings, since the times of peak bus ridership are also those of peak car use. This potential confounder was controlled for by including a dummy variable representing trips in the early morning or evening periods, when congestion is much lower. An alternate specification, using a dummy variable for the peak period alone, was tested, but it had no

¹¹ The automatic vehicle monitoring (AVM) system does, however, detect when the doors are open.

¹² The study was conducted on July 18, 2003 between 8 a.m. and 9:30 a.m for both inbound and outbound directions at all Silver Line stops between Dudley Station and Chinatown. Draft Environmental Impact Report (DEIR) for Urban Ring Phase 2, http://www.mbta.com/projects_underway/urbanring_docs.asp

¹³ PM peak dwell times on the Las Vegas MAX range from 12 seconds in the off-peak direction to 17 seconds in the peak direction. Data from Federal Transit Administration, Metropolitan Area Express (MAX), Bus Rapid Transit (BRT) Demonstration Project Evaluation, draft report prepared by Booz Allen Hamilton, Inc., 2005.

explanatory power. In other words, travel times in the peaks were not significantly different than the midday, but the peak and midday combined were significantly different from the early morning and evening periods.

**Figure 16: Regression Model Results of Running Time
(CTPS Ridecheck Data)**

| | Units | Inbound Trips | | | Outbound Trips | | |
|----------------------------------------------------------|-------------|---------------|-------|-------|----------------|-------|-------|
| | | 2001 | 2003 | 2005 | 2001 | 2003 | 2005 |
| <i>Intercept</i> | min. | 15.81 | 12.70 | 12.61 | 16.68 | 12.21 | 14.14 |
| | t-statistic | 24.64 | 29.20 | 18.63 | 27.05 | 29.58 | 27.95 |
| <i>Boardings</i> | min. | 0.10 | 0.08 | 0.11 | 0.08 | 0.07 | 0.08 |
| | t-statistic | 6.78 | 8.65 | 9.97 | 5.13 | 9.05 | 8.72 |
| <i>Early-Late*</i> | min. | -3.75 | -3.24 | -3.37 | -5.37 | -1.73 | -3.20 |
| | t-statistic | -6.52 | -7.63 | -5.38 | -8.51 | -4.29 | -6.43 |
| Adjusted R squared | | 0.59 | 0.56 | 0.64 | 0.54 | 0.46 | 0.51 |
| observations** | | 131 | 163 | 166 | 125 | 172 | 167 |
| Calculations | | | | | | | |
| Mean boardings/ peak or midday trip | boardings | 41 | 44 | 56 | 31 | 46 | 48 |
| Seconds/pass | sec. | 5.7 | 4.7 | 6.7 | 5.1 | 4.3 | 4.9 |
| Predicted travel time at own mean boardings/trip (min.) | min. | 19.7 | 16.1 | 18.9 | 19.3 | 15.6 | 18.1 |
| Predicted travel time at 2001 mean boardings/trip (min.) | min. | 19.7 | 15.9 | 17.2 | 19.3 | 14.5 | 16.7 |

Note: *dummy variable equal to 1 for trips in early AM and evening periods. **some trips were missed.

Dependent variable is running time in minutes.

Source: Calculations using CTPS ridecheck data

The regression results for inbound and outbound weekday trips using CTPS ridecheck data are shown in Figure 16. The "intercept" row can be interpreted as running time in minutes if there were zero boardings. The boardings row shows the delay in minutes per passenger (delay in seconds is shown below). The Early-Late row shows that early morning trips and late evening trips average about 3 minutes less than other trips, controlling for the number of boardings. This can be interpreted as the potential time savings from reducing traffic congestion delay. Adding the Early-Late figure to the Intercept figure gives the average travel time in the early AM or late evening periods if there were no passengers.

Delay per passenger (seconds/pass.) was reduced by a full second for inbound trips in 2003 compared to 2001, and almost as much for outbound trips. This reduction in delay could be the result of the introduction of low-floor vehicles, which tend to reduce both boarding and alighting time. It could also be the result of the reduction in the number of stops. With fewer stops, there are fewer occasions when a bus stops for a single passenger to board or alight, and thus the correlation between the number of boardings and alightings and delay due to acceleration and deceleration delay is reduced, possibly approaching zero.

Delay per passenger increased in 2005, reflecting the impact of implementation of the AFC system. The effect was most pronounced for inbound trips. This could be because inspectors at Temple Place permit rear door boarding on outbound trips (the predominant flow of trips is inbound in the morning and outbound in the evening). The model also allows one to conduct a thought experiment: what would have been the running times in 2003 and 2005 if boardings per trip had held constant? These figures, shown in the last row of the table,

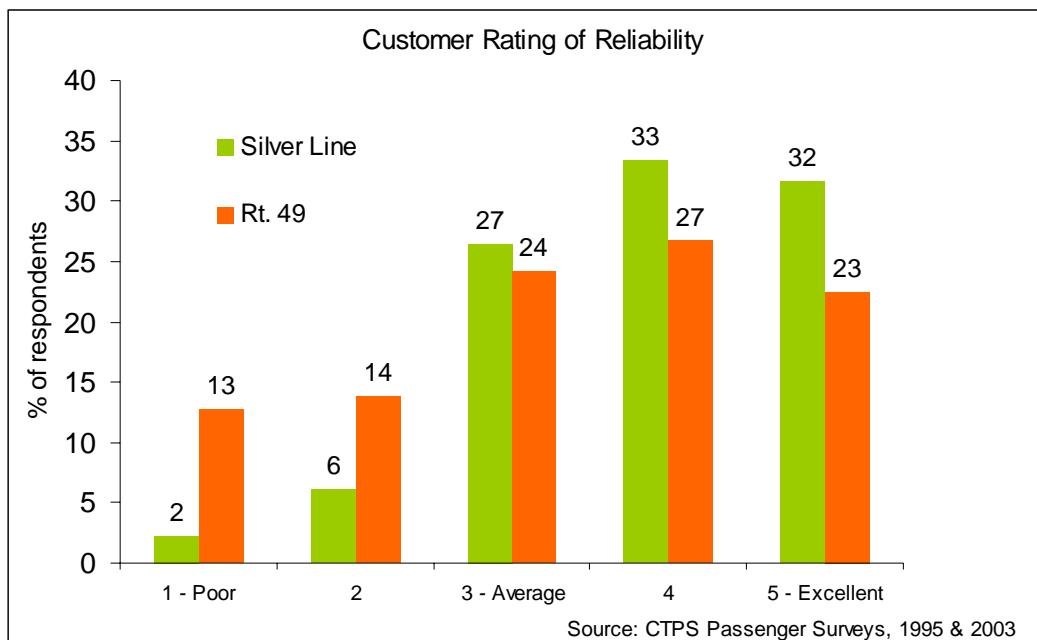
show that mean running time would have been reduced further. The change is greatest for outbound trips, because there was a much larger increase in average number of boardings per trip.

4.2 RELIABILITY

Customer Perceptions

In a 2003 CTPS survey, passengers were asked to rate "Reliability" on a scale of 1 to 5, with 1 being "poor" and 5 being "excellent."¹⁴ Two-thirds of respondents rated the Silver Line as above average (4 or 5). A comparison of these data with results from a 1995 CTPS survey of bus riders is shown in Figure 17. Only 8 percent of respondents rated the Silver Line as below average (1 or 2). By comparison, 27% of respondents thought route 49 was below average, and only half gave it an above-average rating.

Figure 17: Customer Rating of Reliability, Silver Line and Route 49



Running Time Reliability

Improved reliability can also be seen in the reduced variability of running time, as discussed in the previous section. Reducing the variability of running time directly reduces the average waiting time. However, reducing the extremes of running and waiting time is equally important. If service is adequate most of the time, but there are occasionally large gaps or unusual delays, customer perception of the reliability of service may decrease. Spending a very long time waiting is particularly onerous, and may cause riders to abandon the service, even if it is an infrequent occurrence. There was a significant decline in the standard deviation of running time evident in the Spring 2003 counts of the Silver Line compared to

¹⁴ The survey was conducted in June, 2003, from 6 am to 3:30 pm in both directions. CTPS received 850 complete responses, or a bit less than 10% than the estimated 8,775 riders who boarded during that time period. The responses were factored up to total estimated all-day ridership, using weights stratified by direction and time period (Thomas J. Humphrey, February 10, 2004 Memorandum to Maureen Trainor, MBTA, Central Transportation Planning Staff, Boston, Mass.)

Route 49. These gains were considerably reduced in the Spring 2005 counts, especially in the inbound direction (see Figure 18 and Figure 19).

Figure 18: Standard Deviation of Inbound Running Time by Time Period (Various CTPS Ridechecks, Route 49 and Silver Line Washington Street)

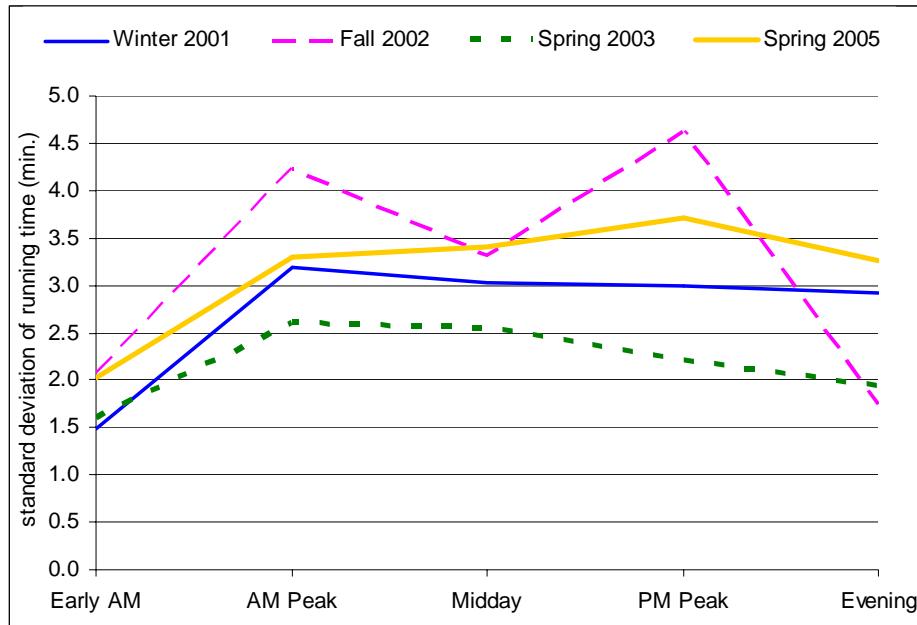
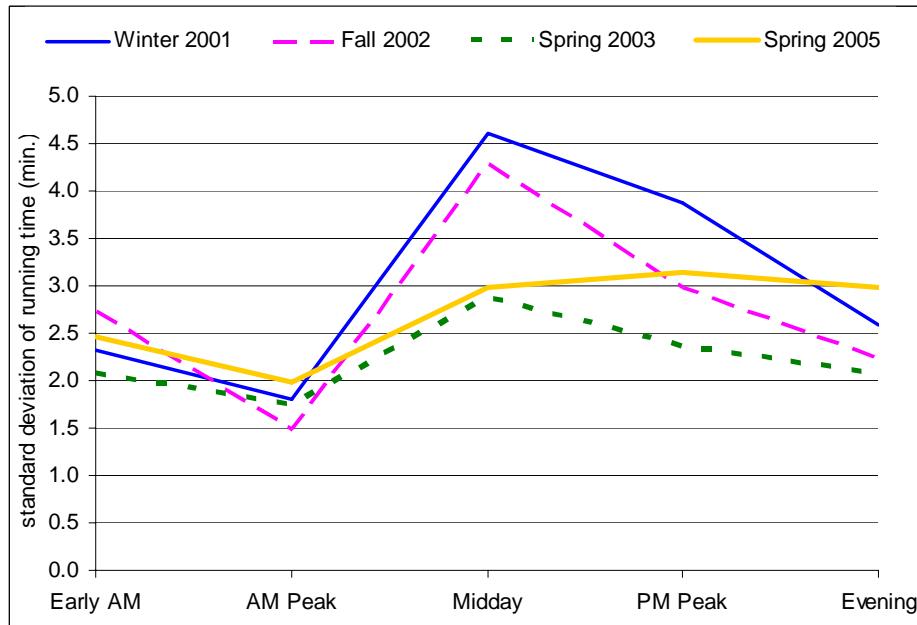


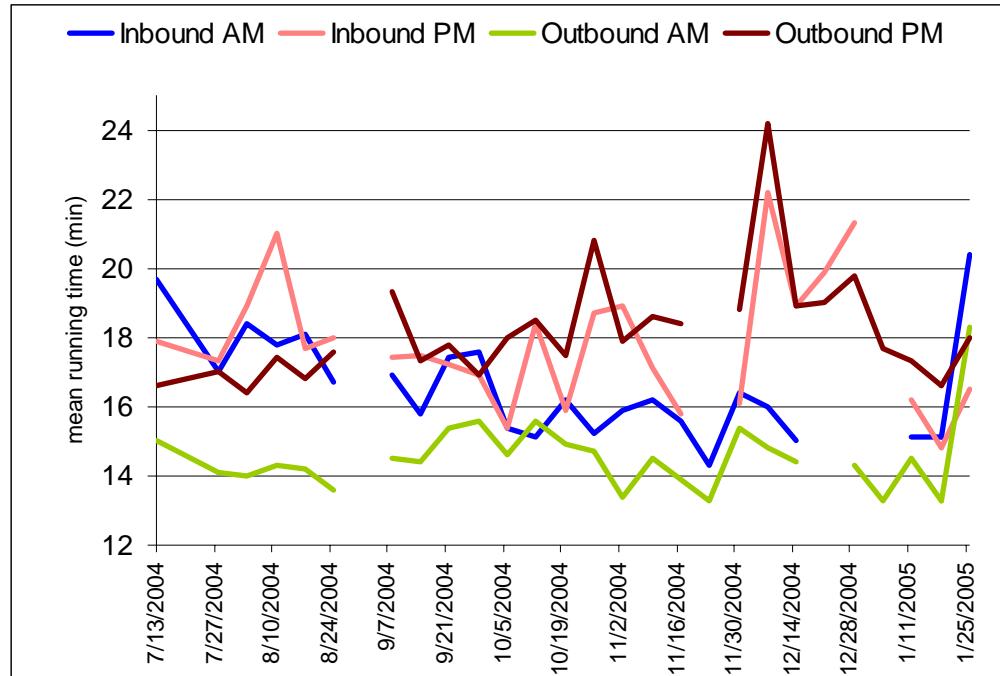
Figure 19: Standard Deviation of Outbound Running Time by Time Period (Various CTPS Ridechecks, Route 49 and Silver Line Washington Street)



Running times may be consistent most days, but particular circumstances such as snow, parades, or severe traffic congestion may disrupt service from time to time. The automatic

vehicle location (AVL) data on running time provide a means for determining the variability of running time over a longer period of time. Figure 20 shows mean running time for the AM and PM peak, inbound and outbound, for Wednesdays from July 2004 through January 2005. The outbound AM trips have the shortest mean running time, and the least variability in running time. There are several days in this period with unusual traffic congestion or snow, resulting in travel times several minutes above normal. There was heavy snowfall that disrupted service on the last day shown; this event lengthened travel times in all periods.

**Figure 20: Mean Running Time by Time Period
(AVL data, Silver Line Washington Street)**



Service Reliability

Another aspect of reliability is the span and frequency of service. By MBTA service policies, "rapid transit" services are operated frequently enough so that customers do not need to consult a schedule during the entire span of service, including late evenings and weekends. This translates into a policy maximum headway of 15 minutes. Very few MBTA bus routes would be able to meet this policy maximum for rapid transit service without an increase in service. The largest increase in service frequency in the transformation of route 49 into the Silver Line occurred during weekend and late night periods.

Providing passengers with comprehensive and accurate information is an important aspect of service reliability. Information increases awareness about the service and also reduces the psychological cost of taking transit by making it easy to use and reducing the anxiety that accompanies uncertainty. The Silver Line has comprehensive information about the service and the system at stops and a strip map and stop announcements on board the vehicle. In addition, real-time bus arrival information will be added when system testing is completed satisfactorily.

4.3 IDENTITY AND IMAGE

The idea of the Silver Line was to make a rubber-tired service that would be as good as rail service. All of the MBTA core system rail services have a color-coded name. Thus the concept was to add an additional color-coded branch to the system, a "fifth rapid transit line." According to the MBTA, the Silver Line name was chosen because "From racing cars to rockets, the use of the color silver symbolizes speed and high-technology." It is also true that all of the primary colors (red, blue, green, orange, yellow, and purple) were already in use for other parts of the system.

The Silver Line is the first bus service for which the MBTA has conducted a major marketing campaign. The campaign included the creation of a Silver Line logo (see Figure 21) used on signs, and web and print materials. There is a Silver Line website with a separate URL from the regular MBTA website (www.allaboutsilverline.com). There was an opening day event at Dudley Square with entertainment, face painting, free service, give-aways, and a ribbon-cutting. The marketing campaign cost about \$170,000, including the kickoff event, print ads, and billboards.

Figure 21: Silver Line Logo



A key component of the branding strategy was to have a vehicle that did not look like an ordinary bus. The service would be inaugurated with new vehicles, both the first low-floor and the first natural gas buses to enter into regular service in the MBTA system. All Silver Line vehicles are painted in a distinctive silver livery. Because the articulated CNG buses planned for the service were not available in time for the opening, new 40 ft. buses (but low-floor and CNG) were used temporarily for one year, after which most were repainted in standard MBTA yellow livery to be used elsewhere.

When the Silver Line concept was adopted, the MBTA decided to use the name for both the Washington Street Replacement Service and the South Boston Piers Transitway, which had previously been unconnected projects. The plan is to eventually link the two with additional tunneling. This third phase of the Silver Line is in the planning process as of this writing and is expected to be complete in 2013. The public information campaign provided information about both phase I and II. The title of the campaign, "Dig for Silver," emphasized the bus tunnel, a key component of Phase II.

The opening of the second phase of the Silver Line in 2004 created the possibility of confusion with two unconnected services with the same name. Therefore the decision was taken to call the first phase "Silver Line Washington Street" and the second phase "Silver Line Waterfront."¹⁵

¹⁵ There are three branches of the Silver Line Waterfront, SL1, SL2, and SL3, and a fourth branch is planned.

Other BRT deployments have branded BRT service as a quality of service rather than a particular route (brand name examples include Express, Rapid, Max, B-Line, and Quality Bus).

By being part of the “rapid transit” system, the Silver Line, alone among the bus routes, is included in the system spider map displayed at all stations and in the Rapid Transit route schedule pamphlet. Transfer opportunities to the Silver Line are announced on rapid transit services.

The decision to create a “fifth rapid transit line” sets up the Silver Line for comparison with the other lines. *The Boston Globe* published an article comparing travel time on the Silver Line from Dudley to downtown to travel time from a similar distance away from downtown on the Red, Orange, and Green lines.¹⁶ The *Globe* found that the Red and Orange lines, both heavy rail, were faster. The article did not point out the large differences between routes running on the surface and those with their own rights of way. In fact, the *Globe* found that travel time on the Green Line, a light rail route that runs partly on the surface, was similar to the Silver Line.

The initial response to the Silver Line was favorable. A sidewalk survey conducted by the MBTA’s marketing department found that 41% rated the service as excellent, 28% very good, 21% good, 6% okay, and only 4% said poor. Also, 56% said that the Silver Line was better than bus 49, 37% had no opinion, and only 7% said no. The most popular response as to why it was better was the new vehicles.¹⁷

Historic Markers

Historic Markers also helped create the identity and image of the Silver Line. This project consists of 32 panels, each unique, installed on one facet of each kiosk located at the stop, and six medallions installed in the sidewalk along the route. One of the historic marker panels is shown in Figure 22. The materials were developed during a two-year process involving residents and community groups, and took advantage of images from historical archives. Each panel provides historical information and images on a theme: Architecture, Commerce, Institutions, Made Land, People, Revitalization, Roxbury Leaders, Roxbury Landmarks, Social Life, Transportation, and Urban Renewal. There are also several “Transitions” panels which have location-specific content and compare today’s Washington Street to historical conditions as far back as the 18th century. A book compiling the images is planned. Neighborhood maps were also installed on the kiosks as part of the project. The cost was about \$60,000 for the medallions and \$132,000 for the historic panels and neighborhood maps.

¹⁶ Anthony Flint. *Silver Line not the shiniest commute. Other T branches go downtown faster.* *The Boston Globe* 02/23/2004.

¹⁷ MBTA Marketing Communications, *Silverline, Draft: Customer Survey*, August 2002.

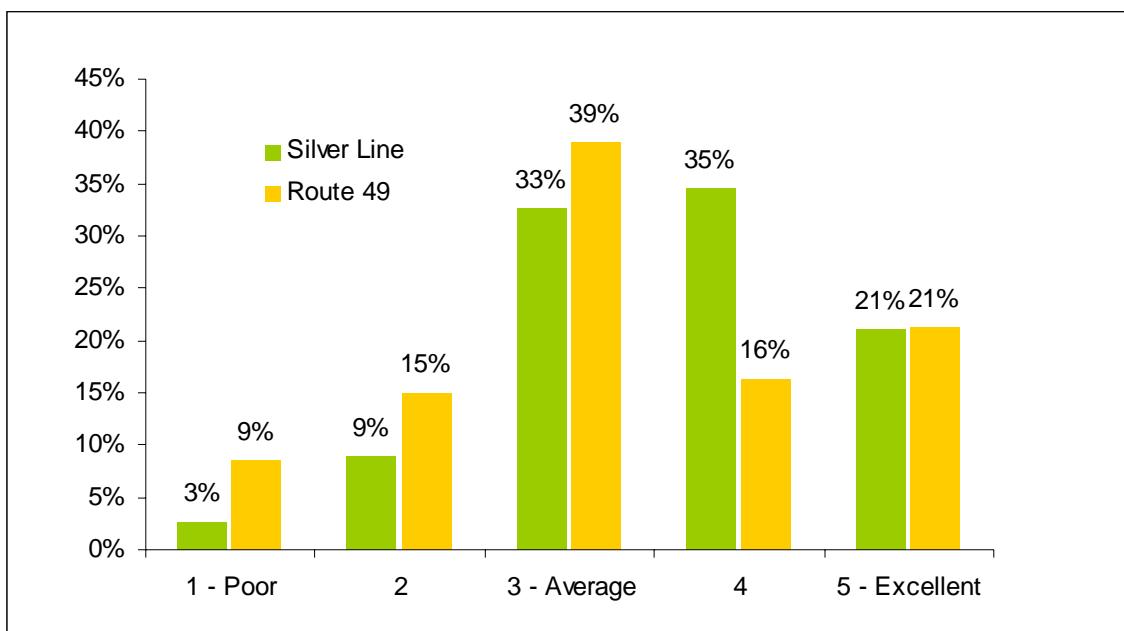
Figure 22: One of 32 Different Historic Markers Installed on Station Kiosks



4.4 SAFETY AND SECURITY

The MBTA operates its own police force. There is a police presence at Dudley Station, the terminus of the Silver Line. Both the 2003 survey of the Silver Line and the 1995 survey of bus route 49 asked respondents to rate personal safety on a scale of one to five. The percent rating the route as below average (1 or 2) decreased from 24% on Route 49 to 12% on the Silver Line, as shown in Figure 23. The percent rating the service above average in personal safety (but not excellent) (4) increased from 16% to 35%. A comparison of respondents in 2003 who has previously used Route 49 to those who did not shows that those new to the corridor gave the Silver Line higher marks for personal safety than those who had previously used Route 49 to make the same trip. It is possible that stop consolidation compared to Route 49 may have improved feelings of safety by reducing the likelihood of riders having to wait alone at a stop.

Figure 23: Customer Rating of Personal Safety on Silver Line and Route 49



4.5 CAPACITY

As of May 2005, Silver Line Washington Street operated at a maximum frequency of 16 trips per hour (between 7:30 and 8:30 am inbound, at slightly less than four minute headways). The 60 ft. buses have 57 seats and can carry a legal maximum of 22 standees. With the current maximum trip frequency, Silver Line Washington Street can accommodate 1,264 passengers per hour in each direction. Service frequency could be increased if warranted by additional demand.

5.0 ASSESSMENT OF SYSTEM BENEFITS

BRT systems provide five major system benefits:

- Higher ridership
- Cost efficiency
- Operating efficiency
- Transit-supportive land development
- Environmental quality

The purpose of this section is to describe the system benefits attributable to the introduction of the Silver Line and assess how BRT system elements and performance characteristics contribute to that system benefit.

5.1 HIGHER RIDERSHIP

Attracting higher ridership is perhaps the most important objective of any new rapid transit investment. Any new transit service may attract three types of trips:

- Existing transit trips that divert to the new system from other services;
- New or "induced" trips that were not made before by transit or any other mode;
- Trips that were previously made by another, non-transit mode (drive alone, carpool, walk or bicycle).

These increased ridership levels are achieved through the combined effects of travel time savings, service reliability, the identity and image of the service, and the safety and security of the service. The following discussion presents the ridership changes from the prior service (Route 49) to Silver Line Washington Street.

Average Daily Boardings

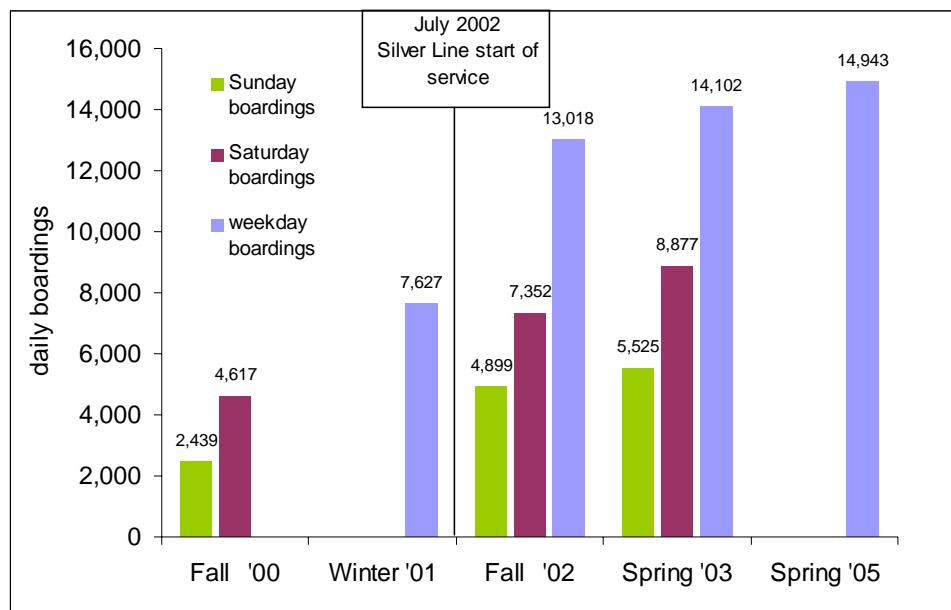
The Central Transportation Planning Staff (CTPS) conducted ridechecks of Route 49 weekdays in the Winter of 2001.¹⁹ The first ridechecks for the Silver Line were conducted in Fall 2002. These were followed by subsequent checks in Spring 2003 and Spring 2005. Weekend ridership was counted in Fall 2000 and then as part of the complete Silver Line checks in Fall 2002 and Spring 2003. Average daily ridership as counted during these checks is shown in Figure 24. Comparing 2005 to 2001, weekday ridership nearly doubled (up 96%). However, most of this increase occurred by Fall 2002, the first count following service opening. Saturday boardings increased 92% and Sunday ridership increased 127%. Weekend ridership may have grown more, as weekday did, between 2003 and 2005.

MBTA staff believe that the 2005 counts may reflect a decline in ridership from an earlier (unmeasured) peak due to increased delay from the Automatic Fare Collection pilot

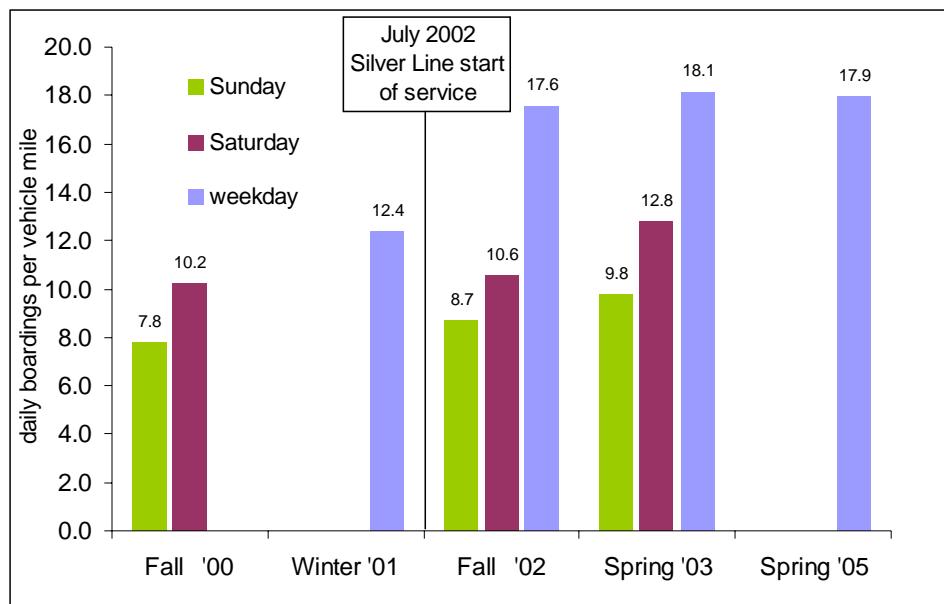
¹⁹ *Ridership data are limited to manual checks that are conducted infrequently. If Automatic Passenger Counters are installed on the Silver Line fleet, daily (or even hourly) ridership could be reported, enabling a much more complete picture of the evolution of ridership over time and in response to system changes.*

program. As noted in the Travel Time section above, the 2005 data show an increase in average running time and a decrease in reliability, as measured by the standard deviation of running time. As the AFC system is improved, ridership may increase further. In comparing the 2005 ridership to the 2003 or earlier counts, one should be aware that the MBTA bus fare increased from \$0.75 to \$0.90 as of January 1, 2004. After adjusting for inflation, the real fare increase comparing Spring 2003 and Spring 2005 was 13%. Assuming a fare elasticity of -0.36, one would have expected ridership to decline 5%. Instead, it increased 6%.²⁰

Figure 24: Daily Boardings, Silver Line Compared to Route 49



²⁰ This fare elasticity for U.S. urban areas of 1 million or more comes from the American Public Transit Association, Fare Elasticity and Its Application to Forecasting Transit Demand <http://www.apta.com/research/info/online/elastic.cfm>

Figure 25: Boardings Per Vehicle Mile, Silver Line Compared to Route 49

Vehicle miles of service increased significantly compared to Route 49. In Figure 25, boardings per vehicle mile of service are shown for the same time periods as the previous figure. This measure shows that there was a very sharp increase in intensity of use during weekdays when the Silver Line was launched. In other words, there were more riders per trip in addition to more trips. Weekday intensity of use (boardings per vehicle mile) compared to Route 49 was up 41% in 2002 and up 45% in 2005. Most of the weekday increase in use since the initial conversion to the Silver Line is related to more service offered—boardings per vehicle mile of service was relatively flat. Weekend ridership per vehicle mile, on the other hand, initially grew more modestly, but increased notably in the 2003 counts, the most recent available. Weekend service, which previous to the conversion had been much less frequent than weekday service, grew dramatically with conversion to the Silver Line. Intensity of use did not grow quite as fast as on weekdays, but it was up 25% by 2003. Notably, it took somewhat longer for this ridership to build, presumably as people discovered that weekend service was almost as frequent as weekday service, a major change compared to Route 49, particularly in regard to Sunday service.

Where Did the New Riders Come From?

A passenger survey conducted by CTPS in 2003 asked respondents to specify the mode they previously used to make the trip on the Silver Line before service started.²¹ The survey allowed respondents to report all previous modes used. For this report, the modes were retabulated to show the primary mode taken (making the total add to 100%). These results are shown in Figure 26. More than half the respondents were previously Route 49 riders. This figure is reasonable given the ridecheck data showing that ridership doubled. Among those who were not previously Route 49 riders, about half previously used the Orange Line

²¹ CTPS conducted a second passenger survey in May 2005, but results were not available in time for use in this report.

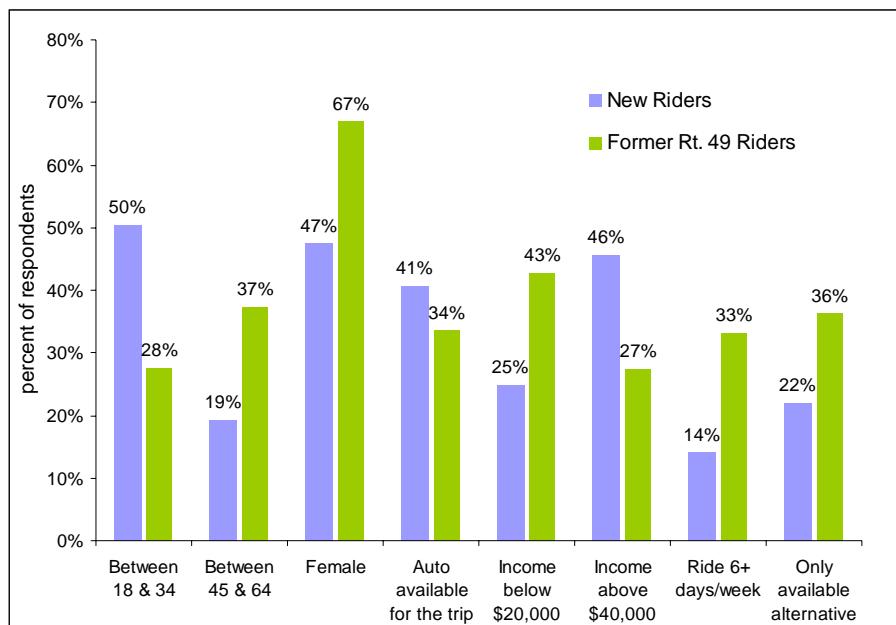
or some other MBTA service. Only 16.6% were new to the system: those previously walking or driving, and those not making the trip before (and a few people using other modes). Only 1.8% previously drove alone, but this rate is not surprising given that downtown Boston has some of the highest parking prices in the nation, and that those who have employer-paid parking available were unlikely to switch to the Silver Line.

**Figure 26: Previous Mode of Silver Line Riders, Spring 2003
(CTPS survey)**

| | Weighted count | % | Subtotal |
|-------------------------------------|-------------------|-------|----------|
| Took Route 49 | | | 55.3% |
| did not use Orange Line | 3487 | 41.9% | |
| did use Orange Line | 1111 | 13.4% | |
| Did not Use Route 49, but used MBTA | | | 28.1% |
| Orange Line | 1399 | 16.8% | |
| Other MBTA rail | 303 | 3.6% | |
| Other MBTA bus | 634 | 7.6% | |
| Did not use MBTA | | | 16.6% |
| Walked only | 558 | 6.7% | |
| Drove alone | 146 | 1.8% | |
| Did not make trip | 656 | 7.9% | |
| Other (Taxi, Bike, Shuttle) | 24 | 0.3% | |
| Total Responses | 8318 | 100% | 100% |
| No response | 437 | | |
| Total Boardings | 8755 | | |

The CTPS survey allows us to compare Silver Line riders who previously used Route 49 to those who were new to the route. These comparisons are shown in Figure 27. The new riders are younger, more male, and have higher income. They are more likely to have an auto available for the trip, less likely to use the route more than five days a week, and were less likely to say that the Silver Line was the only available alternative. In short, the new riders are more like MBTA subway system riders than they are like MBTA bus system riders.

**Figure 27: Selected Characteristics of New Riders Compared to Former Route 49 Riders
(2003 CTPS Passenger Survey)**



What stop locations have the new riders come from? Since the number of stops was reduced from 20 to 13, grouping the stops in regions makes sense to compare Route 49 boardings and alightings to Silver Line boardings and alightings. Figure 28 shows the net change in boardings and alightings on the inbound route; Figure 29 shows the same thing for the outbound route. The route is directional: the majority of riders go inbound in the morning and outbound in the evening. Dudley Square is a major bus transfer point. Tabulations from the 2003 Passenger Survey show that 62% of Silver Line riders boarding at Dudley transferred from a bus; 65% of those alighting at Dudley were transferring to a bus. More than 1,300 new boardings inbound and alightings outbound were at Dudley. There were almost no ridership gains between Ruggles and Lenox Streets. One explanation is that some new riders from this area may be walking to Dudley to board. However, this area has the most vacant or under-used lots and parks and has had much less new development than other sections of the route.

Figure 28: Change in Boardings and Alightings, Silver Line (2003) Compared to Route 49 (2001), Weekdays, Inbound

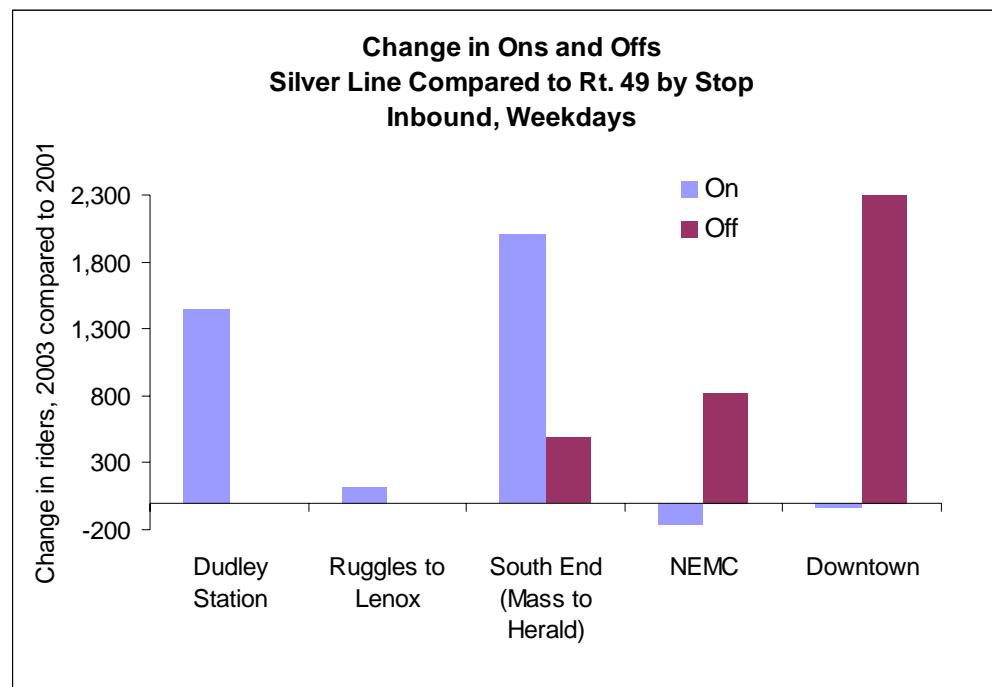
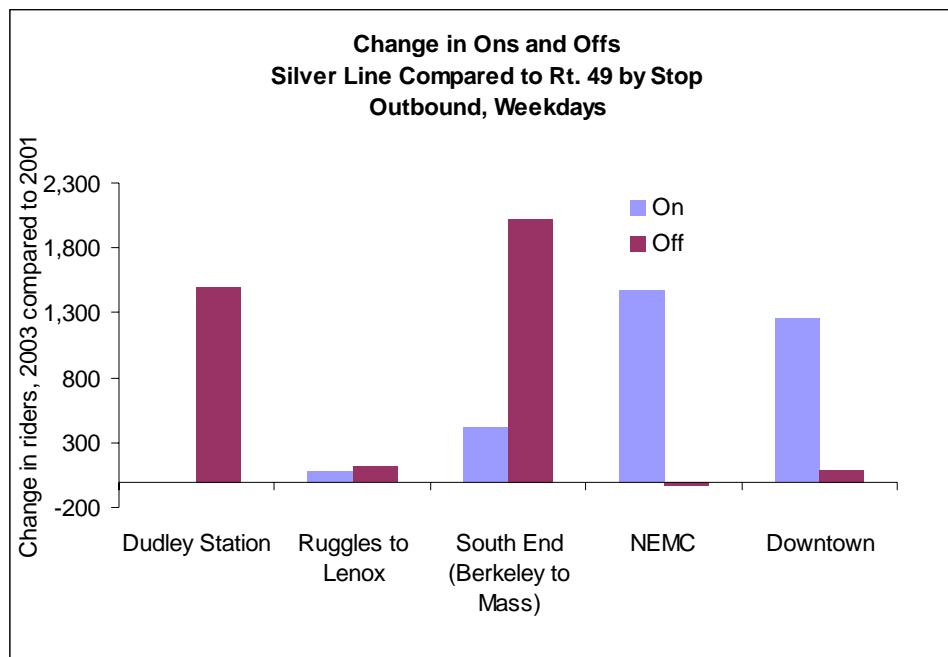


Figure 29: Change in Boardings and Alightings, Silver Line (2003) Compared to Route 49 (2001), Weekdays, Outbound



The South End, from Massachusetts Avenue to Herald Street, accounts for a substantial number of new riders. Most of the new activity consists of boardings inbound and alightings outbound. This suggests that most of the trips are home-based, given that the South End is predominantly residential. Some of the new riders boarding in the South End may have previously used bus route 43, which serves Tremont Street, one long block from the Silver Line route. The increase in residences and commercial activity along Washington Street in the South End in the past few years may also account for some of the new ridership.

There was a large increase in inbound alightings at New England Medical Center (NEMC) and Downtown. According to the passenger survey, 37% of inbound riders getting off at NEMC transferred to the Orange Line. Of those exiting at Chinatown, 13% transferred. Nearly one-quarter (24%) of inbound riders alighting at Downtown Crossing transferred to the subway. The Downtown Crossing transfer would have required payment of an additional full subway fare for Route 49 riders, but is completely free on the Silver Line.

The number of inbound boardings at NEMC actually declined with the implementation of the Silver Line. NEMC is only a few blocks from the downtown terminus of the route. One would think that few customers would prefer waiting for the bus to a 5-minute walk. Prior to the implementation of the Silver Line, however, NEMC was not directly served outbound. It is likely that some passengers were boarding inbound for the outbound trip instead of walking several blocks to the outbound station. With the Silver Line, there was no need to do this because the station was served directly outbound. These riders would then show up as outbound boardings. In fact, the number of new outbound boardings at NEMC exceeds the number of new boardings downtown.

5.2 CAPITAL COST EFFECTIVENESS

This project was effective in attracting riders, and capital costs were much lower than projects that involve extensive construction of exclusive rights-of-way. The cost of shelters, kiosks, stop amenities, and roadway work attributable to the transit project was \$13.4 million. Dividing by 4.736 directional route miles, this amounts to a cost of \$2.84 million per directional route mile. Including vehicle costs, the total capital cost was \$27.3 million, or \$5.77 million per directional route mile. However, there are several reasons to believe that some capital cost items contributed more than others to the benefits observed.

New vehicles were an essential component for passenger comfort and project marketing and identity. The \$13 million expended for 17 articulated CNG buses was half the total capital cost of the project. However, most of the ridership increase was obtained before the articulated buses were deployed. It is possible that 40 ft. buses on shorter headways could have met demand for the service. However, there was significant crowding and customers unable to board due to lack of capacity before the larger vehicles were deployed. Avoiding articulated buses, if possible, would have significantly reduced the capital expense. More significantly, the use of natural gas buses increased operating and maintenance costs compared to clean diesel.²² CNG buses are significantly more expensive than diesel buses and also required the MBTA to construct new maintenance, fueling, and depot facilities. These capital costs include \$48 million to retrofit three bus facilities (Cabot, Charlestown, and Everett) to CNG compatibility. Another \$164 million was budgeted to construct two new CNG bus facilities (Southampton and Arborway); however, a significant portion of this would have been expended even without conversion to CNG in order to replace the aging Bartlett garage. All Silver Line vehicles (both phase I and phase II) are garaged at the Southampton Street bus facility, which had a capital cost of \$54 million. This garage also services 27 articulated CNG buses used on Route 39.

Of the \$13 million in capital costs, \$2.6 million was used for custom-built shelters that were designed with input from the public design process. These shelters have been criticized for providing insufficient protection from rain and wind.²³ By contrast, the new shelter used at the Temple Place stop and elsewhere in Boston is protected by glass on three sides. These shelters, constructed, installed, and maintained by Wall USA, are completely supported by advertising revenues. Using this arrangement would have provided similar benefits and reduced the capital cost for shelters significantly.

Significant cost savings were realized because the Silver Line project was planned in tandem with the reconstruction of Washington Street. Incorporating the transit project in the road design meant that design and planning costs were combined. Capital investments necessary for the transit project, such as moving curbs and installing new signals, were made with little additional expense.

²² MBTA staff have indicated that operating costs for CNG are higher than for comparable diesel buses, but they have not provided specific figures. Other transit agencies have found similar results.

²³ An August, 2002 survey by the MBTA's marketing department found that "Many of the riders would prefer that the stations were partially enclosed and that the roofs were lower to provide better protection against the elements." This sentiment was also reported by Robin Washington in The Boston Herald, June 2, 2003.

5.3 OPERATING COST EFFICIENCY

Operating cost efficiency is defined in this context as the unit cost to produce a unit of service output from a unit of service input. Operating efficiency is assessed according to the following transit performance indicators, typically used throughout the industry to measure service productivity and operating cost efficiency:

- Operating cost per vehicle hour (cost effectiveness)
- Operating cost per vehicle mile (cost effectiveness)
- Passengers per vehicle hour (service effectiveness)
- Average cost per passenger
- Net subsidy per passenger

According to 2003 data presented as part of the MBTA's 2004 Service Plan and summarized in Figure 30, the average cost of weekday bus service systemwide is \$102/hour. The Silver Line Washington Street had an average cost of \$109/hour, reflecting in part the higher costs of CNG compared to diesel service. The bus system average operating cost per vehicle mile was \$10. The Silver Line had the second highest cost per vehicle mile, \$17. These measures of vehicle hours include layover and deadhead time. Weekend unit costs were lower for the Silver Line, its predecessor, and the system as a whole.

Figure 30: Operating Costs for Silver Line (2003), Route 49 (2001) and MBTA Bus System (2003)

| | Route # | Vehicle | Vehicle | Board- | Revenue | Rev/ | Cost/ | Cost/ | Gain | Pass / | Pass / | Recovery |
|----------|---------|---------|---------|-----------|---------|----------|--------|--------|------|--------|----------|----------|
| | | hours | miles | | | | | | | veh hr | veh mi | ratio |
| Weekday | Silver | 120 | 768 | \$13,041 | 14,102 | \$5,923 | \$0.42 | \$0.92 | \$17 | \$109 | (\$0.50) | 117.4 |
| | Rt. 49 | 77 | 614 | \$7,822 | 7,627 | \$3,661 | \$0.48 | \$1.03 | \$13 | \$102 | (\$0.55) | 99.5 |
| | System | 6818 | 69,008 | \$694,739 | 348,755 | 184,768 | \$0.53 | \$1.99 | \$10 | \$102 | (\$1.46) | 51.2 |
| Saturday | Silver | 104 | 696 | \$10,043 | 8,877 | \$3,728 | \$0.42 | \$1.13 | \$14 | \$96 | (\$0.71) | 85.0 |
| | Rt. 49 | 75 | 452 | \$7,224 | 4,617 | \$2,216 | \$0.48 | \$1.56 | \$16 | \$96 | (\$1.08) | 61.4 |
| | System | 4032 | 41,093 | \$352,808 | 176,342 | \$86,728 | \$0.49 | \$2.00 | \$9 | \$88 | (\$1.51) | 43.7 |
| Sunday | Silver | 83 | 565 | \$8,043 | 5,525 | \$2,321 | \$0.42 | \$1.46 | \$14 | \$97 | (\$1.04) | 66.6 |
| | Rt. 49 | 54 | 312 | \$5,147 | 2,439 | \$1,171 | \$0.48 | \$2.11 | \$17 | \$96 | (\$1.63) | 45.5 |
| | System | 2,029 | 21,774 | \$181,768 | 92,560 | \$44,729 | \$0.48 | \$1.96 | \$8 | \$90 | (\$1.48) | 45.6 |

Notes: Silver Line boardings from Spring 2003; Rt. 49 boardings from Fall 2000 (Sat. & Sun) and Winter 2001 (weekday).

Revenue based on multiplying MBTA's assumed average revenue per passenger by boardings.

Source: MBTA 2004 Service Plan

Passengers per vehicle hour is a measure of the intensity of service usage. With 117 passengers per vehicle hour, the Silver Line had the highest intensity of use of any MBTA bus route. One other route had 90 passengers per vehicle hour and the next highest 11 routes had between 70 and 80. In 2001, bus route 49 (the Silver Line's predecessor) had nearly 100 riders per vehicle hour, more than any other route but 15% less than the Silver Line in 2003. By comparison, the MBTA system average for light rail was 190 riders per vehicle mile and 156 for heavy rail.²⁴

²⁴ National Transit Database, 2003 Report, Profiles, 50 Largest Agencies.

[http://www.ntdprogram.com/NTD/Profiles.nsf/2003+30+Largest+Agencies/1003/\\$File/1003.pdf](http://www.ntdprogram.com/NTD/Profiles.nsf/2003+30+Largest+Agencies/1003/$File/1003.pdf).

These figures are based on all service operated over the year, whereas the figures from the Service Plan are based on weekday service only.

Although the Silver Line has higher than average operating costs, it has much higher than average usage compared to other bus lines. A combined measure of cost effectiveness and service effectiveness is average cost per passenger. At \$0.92 per weekday boarding, the Silver Line had the lowest average cost per passenger of any weekday MBTA bus route in 2003. The system average cost was \$1.99 per passenger on weekdays. Based on 2001 ridership data, and using the system average cost per vehicle hour, bus 49 had costs of about \$1.03 per rider. On weekends, the Silver Line cost per passenger was considerably higher than weekdays. However, assuming similar costs per vehicle mile for Route 49, the net cost per passenger dropped considerably—again due to the increase in ridership in excess of the increase in vehicle miles.

For the Service Plan calculations, the MBTA assumes an average fare of \$0.48 per boarding for all bus routes, except those that accept a subway pass. For these routes, which include the Silver Line, the MBTA assumes an average fare of \$0.42. Because subway passes were not valid on Route 49, and a paper transfer to rail was available in only one location, it is assumed that the average fare on Route 49 would be \$0.48.

Combining the average cost per rider with the average revenue per rider gives the net gain or loss per rider. In most cases there is a net negative cost (subsidy) per rider. In weekday service, the Silver Line Washington Street in 2003 had the lowest net cost per passenger of any MBTA bus route except routes 501 and 502, which are high-ridership express bus routes that charge a premium fare.²⁵ On Saturdays, the Silver Line had the 5th lowest cost per passenger of all MBTA bus routes. On Sundays, the Silver Line was the 14th lowest.

In both weekday and weekend service the implementation of the Silver Line lowered the net subsidy per passenger. This was because the increase in riders was larger than the increase in operating costs. This represents a shift to more efficient use of resources.

²⁵ Assuming an average fare of \$1.50, the 501 and 502 had revenue in excess of operating costs, unlike all the other routes, which lost money.

5.4 TRANSIT-SUPPORTIVE LAND DEVELOPMENT

Public transit investments can help promote corridor redevelopment. Equally important, development and re-development of available and under-used sites is essential to the success of transit, particularly if the development is designed at a pedestrian scale and minimizes automobile parking.

South End

The Washington Gateway Main Streets program was established in 1997 to promote urban improvement and commercial activity along the Washington Street Corridor from Herald Street to Melnea Cass Boulevard, the major portion of the Silver Line route.²⁶ In the mid-1990s, there were many vacant blocks and abandoned buildings along the corridor, and there was little commercial activity. The reconstruction of the streetscape was a key factor in the improvement of the district. Prior to construction, Washington Street still had remnants of the supports of the elevated railroad and both the roadway and sidewalks were in poor condition. The Silver Line project included curb-to-curb resurfacing of the roadway, wider brick sidewalks, and historic lighting fixtures.

Between 1997 (when the Silver Line was in planning) and 2004, the following land use changes occurred in the district:²⁷

- \$250 million in new real estate construction and \$93 million in rehabilitation;
- 1,731 new or rehabilitated housing units, 900 designated as "affordable";
- 128,000 square feet of new or renovated retail space;
- \$7 million in improvements to commercial spaces.

Notable new construction projects include the South End Community Health Center, with ground level retail, and the Rollins Square (183 units), the Savoy (13 units) Wilkes Passage (155 units), and Dover Lofts (16 units) condominiums, also with ground-level retail. Historic rehabilitation projects include:

- Minot Hall, 1723 Washington Street, 45 condos, including new construction;
- Porter House, 1721 Washington Street, 5 condos;
- Washington Union, 1724 Washington Street, Federal style building
- Alexandra Hotel, 1759-1769 Washington Street

Gateway Terrace is a three building complex on Washington and East Berkeley streets that will create 133 condominium lofts by the end of 2005, for a total project cost of \$60 million. In May 2005, Washington Street won a Great American Main Street Award from the National Trust for Historic Preservation.

26 The Washington Gateway Main Streets program maintains a website at <http://www.gatewaymainstreet.org>

27 According to the Washington Gateway Main Streets program, <http://www.gatewaymainstreet.org/>

Dudley Square

Dudley Square has not seen the same level of redevelopment as the South End, but development activity picked up markedly in 2004 and 2005. The Dartmouth Hotel at 49 Warren Street, an 1871 building listed in the National Register of Historic Places, opened in late 2004 after a \$20 million project that included a gut rehab of 45,000 s.f. and a 25,000 s.f. addition. The upper floors contain 45 units of subsidized housing. The lower floors are neighborhood-serving retail. The Hibernian Hall, a long-vacant former dance hall dating from 1913 at 184 Dudley Street, was rehabilitated in 2004 and re-opened as the Roxbury Center for the Arts.

In early 2005, the Gordon-Conwell Theological Seminary announced plans to renovate a 24,000 sq. ft. historic building in Dudley Square, 90 Warren Street, and move its Boston campus there by 2006. In 2005, the Jubilee Christian Church began construction of a new office building on the corner of Warren and Palmer Streets along the Silver Line route near Dudley Station. The church plans to lease 30,000 s.f. of the \$9.2 million building to office and retail tenants. Also in 2005, Central Boston Elder Services Inc. moved to a new \$9.5 million building on Washington Street directly opposite Dudley Station. According to *The Boston Globe*, one reason that the non-profit group chose the new location was "public transportation access that has improved with the new Silver Line bus route." The former Ferdinand's furniture store, which occupies a prime spot in Dudley, has been vacant for many years. A plan to move some state agencies to that location was scrapped in 2004, but the City of Boston announced that it would redevelop the site and relocate city agencies. According to an article in *The Boston Globe*, "the MBTA's Silver Line bus service from Dudley Square to downtown has increased access for residents of the area and for those who might find jobs in Roxbury."²⁸

Demand for residential space near Dudley Square is also high. According to *The Boston Globe*, "Roxbury is on the cusp of a revival, real estate agents say. With housing costs soaring, many first-time buyers are seeing Roxbury as an affordable alternative to other neighborhoods. Among Roxbury's selling points is its proximity to the city's business districts. The new Silver Line makes the daily 2.3-mile commute from Dudley Square to Downtown Crossing in under 20 minutes."²⁹

Development of nearby sites could bring additional ridership to the Silver Line. The parcels on all four corners of the intersection of Washington Street and Melnea Cass Boulevard are vacant and owned by city and state agencies. The land had been cleared in the 1960s to build an interstate highway. These parcels could be developed as transit-oriented uses, with entrances fronting the street and little off-street parking. On the other hand, they could also be developed in relation to Melnea Cass Boulevard, a relatively high-speed roadway that has few commercial uses fronting the street and little pedestrian traffic. Such suburban-style development has parking lots in front, many commercial driveways, and few amenities for transit riders.

²⁸ Thomas C. Palmer Jr., "Seminary will renovate Dudley Square building: Plan is latest move in push to improve lagging part of city." *The Boston Globe*, 1/04/2005.

²⁹ Chris Reidy, "Roxbury revival is taking hold," *The Boston Globe*, 2/20/2005.

Downtown

The downtown end of the Washington Street Silver Line has also witnessed significant development since shortly before the service started running. Some of the major projects directly along the route include:

- Millennium Place, Washington and Boylston, opened in 2001: movie theater, health club, retail, luxury hotel and restaurant, luxury time shares;
- Park Essex (formerly Liberty Place), 640-680 Washington Street, opening 2006: 650,341 ft, 440 rental units, ground floor retail;
- Kensington Place, 659-679 Washington Street: 457,700 ft, 346 rental units, office, ground-floor retail;
- The Opera House, 539 Washington Street, opened 2004: 106,250 ft, renovated historic theater.

This intensified activity will provide a greater market for transit trips along the Silver Line, including both work and non-work trips, since the projects include a mix of housing, retail, office, and entertainment uses.

A summary of major real estate investment from 1997 to 2005 in the area immediately adjacent to the Silver Line route is shown in Figure 31. These figures include all the projects previously mentioned.

Figure 31: Summary of Real Estate Investment Adjacent to Silver Line Route, by Neighborhood

| | New Construction | Renovation | Total |
|--------------------|------------------|---------------|-----------------|
| Downtown-Chinatown | \$704,000,000 | \$37,000,000 | \$741,000,000 |
| South End | \$313,159,000 | \$107,500,000 | \$420,659,000 |
| Dudley Square | \$18,700,000 | \$38,399,000 | \$57,099,000 |
| Total | \$1,035,859,000 | \$182,899,000 | \$1,218,758,000 |

5.5 ENVIRONMENTAL QUALITY

Environmental quality is an indicator of regional quality of life, supporting the health and well-being of the public and the attractiveness and sustainability of the urban and natural environment. There are three potential environmental improvement mechanisms as a result of the implementation of BRT in a corridor:

- Technology Effect – Reduced corridor bus vehicle emissions due to the propulsion technology
- Ridership Effect – Trips diverted from private vehicles which increase transit ridership
- System Effect – Reduced vehicle emissions from reduced congestion

The Silver Line Washington Street project had a direct, technology effect on emissions. Older diesel buses were replaced with new natural gas buses, which offer significantly lower emissions of nitrous oxides and particulate matter, two of the precursors to regional ozone and smog.³⁰

The ridership effect of the project was small, since only 2% of riders previously made the trip by driving alone. However, 41% of new riders and 34% of continuing riders did have an auto available for the trip.

The project did not negatively impact traffic congestion, and may well have reduced it due to improved traffic signals and better on-street parking management. Moreover, the land use changes happening in the corridor, in part because of the project, are likely to have a beneficial impact on emissions over time as auto use in the corridor changes due to redistribution of housing, jobs, and shopping. As the project corridor becomes a more desirable place to live, shop, and work, it will attract more transit-based trips. Already, all three parts of the corridor (Dudley, the South End, and Downtown/Chinatown) have seen significant intensification of uses.

Accessibility to the Silver Line is regularly used in real estate advertisements and “how to find us” directions from commercial establishments. These changes in land use provide an opportunity for future growth in Silver Line use in the near future as more projects come online and more Boston-area residents discover both the new opportunities and how to reach them by Silver Line.

³⁰ However, the use of new diesels with emissions control technologies operating on ultra-low sulfur diesel fuel would have provided similar reductions, at least when the vehicles are new. In fact, the MBTA's most recent bus purchases have been “emissions control diesel,” due to their similar emissions benefits and significantly lower total cost of operation compared to CNG.

6.0 CONCLUSIONS

The Silver Line Washington Street project significantly increased ridership, improved operating cost efficiency, attracted new customers to transit, and greatly improved customer satisfaction. These benefits were accomplished with a relatively modest capital expenditure. There is evidence that the Silver Line has also had a positive impact on transit-supportive land uses in the corridor that may yield long-term environmental improvement. The project has also highlighted some key lessons in the following areas.

6.1 SUMMARY OF LESSONS LEARNED

New vehicles. There were some implementation problems with the new articulated vehicles. The MBTA was able to adapt by using 40 ft. vehicles for the first year and as a backup thereafter. Most of the ridership gains occurred before the articulated vehicles were deployed. However, there was significant crowding and customer pass-ups before the larger buses were available.

Intelligent Transportation Systems. The deployment of ITS technologies was not without problems. The next-bus information and traffic signal priority are not yet operational due to hardware and software problems that are expected to be resolved soon. The AVL system, however, has already proven to be an integral component for daily route management, and contributes to improved planning and scheduling.

Fare Collection. No change in fare collection equipment or methods was planned as part of the transition to the Silver Line. Dwell times were significantly higher than in similar systems that use proof-of-payment fare collection. The deployment of an Automatic Fare Collection pilot program substantially increased boarding times and thereby had a negative impact on reliability and running time. Although the MBTA is working on resolving these problems, the fact that this one change almost wiped out all the prior gains in travel time suggests that a focus on reducing boarding time delay is a key element of BRT systems.

Project Planning. The mandate to produce a bus system that was not "just a bus" but would have the quality of light rail was a key prerequisite to successful system planning. This concept, formally acknowledged by the MBTA, meant that capital improvements that might otherwise have been deemed too expensive for ordinary bus service were sought out. Combining the project with a road construction project meant that there was the flexibility to make changes to the right-of-way that might otherwise have been viewed as cost-prohibitive. The frequency of service was also increased substantially to meet rapid transit standards.

6.2 SUMMARY OF SYSTEM PERFORMANCE

Travel Time. Before the introduction of AFC fareboxes, travel time had been reduced by as much as 25% in the PM peak period compared to the previous bus service, Route 49. There were travel time savings in every time period. The variability of travel time showed an even greater reduction, contributing to improved reliability. This reduction is even greater considering that higher ridership tends to increase travel time. Many of these gains were reversed following the introduction of new fareboxes. However, it is likely that the AFC-related boarding delays can be eliminated with improvements to the system and less use of cash. A proof of payment system with all door boarding could further reduce boarding delay and improve reliability.

Reliability. Two-thirds of riders surveyed rated the Silver Line as excellent or above average in reliability. This is a large improvement over Route 49, which only 50% of riders rated as excellent or above average in reliability. The number of respondents rating reliability as below average dropped from 27% on Route 49 to just 8% for the Silver Line.

Personal Safety. The percent rating the route as below average decreased from 24% on Route 49 to 12% on the Silver Line.

Capacity. The Silver Line, as currently scheduled, can accommodate 1,264 passengers per hour in the peak direction. The frequency of service could be increased with minimal impact on travel time to provide more capacity if there is sufficient demand.

6.3 SUMMARY OF SYSTEM BENEFITS

Ridership. Weekday boardings increased 96% as of May 2005 compared to the previous bus route 49 in 2001. Saturday ridership was up 92% and Sunday ridership was up 127% as of Spring 2003. Boardings per vehicle mile of service increased 45% weekdays and 25% weekends.

More than half (55%) of the ridership in 2003 had previously used the 49 bus. The remaining 45% included former users of other MBTA services (28%), those not previously making the trip (8%), those walking (7%), and those driving alone (2%).

The new riders were younger, more male, and higher-income than those previously using bus 49. They also were more likely to have a car available for the trip and were less likely to use the Silver Line on weekends and to have no other alternative available for the trip.

Capital Cost Effectiveness. The system capital cost was \$2.84 million per directional route mile, not including vehicle costs, or \$5.77 million per directional route mile including vehicle costs. About half the total \$27 million budget was used for 17 articulated CNG buses, the remainder for infrastructure and ITS. The single most beneficial capital investment was the contraflow lane, which enabled a shorter, more direct route bypassing congestion.

Operating Cost Efficiency. Route 49 had previously been one of the most cost-efficient bus routes in the MBTA system in terms of net subsidy per passenger. The Silver Line further reduced subsidy per passenger because ridership grew faster than the increase in service supplied. However, the use of natural gas increases operating costs compared to diesel. (This premium has not been estimated because of lack of data.)

Land Use. From the years just before the opening of the Silver Line to the present there has been a significant increase in real estate development activity along the Silver Line right-of-way in all three neighborhoods the Silver Line serves: Dudley Square, the South End, and Chinatown/Downtown. These improvements include new construction on vacant lots, rehabilitation of historic buildings, and enhancements to retail. The construction activity has created residential units, office space, and entertainment uses, almost all with ground-floor retail totaling more than \$1.2 billion in investment. All of this activity has transformed the streetscape in less than a decade. The new uses are predominantly transit-friendly including entrances on the sidewalk, pedestrian-scale uses, and limited parking behind or below the new structures. Actors in the land development process have cited the Silver Line as a reason for investing in the area.

Environmental Quality. The Silver Line had a direct and immediate benefit on air quality through the replacement of older diesel buses with lower-emission natural gas buses. The numerous land use changes in the corridor have strengthened the transit market, even as the presence of the Silver Line has encouraged transit-friendly development. The longer-term shifts in land use and transportation patterns from the intensification of uses along the Washington Street corridor are likely to have a beneficial environmental impact by increasing the number of Boston-area residents who live and work in transit-friendly neighborhoods, thereby reducing auto use from what it would have been if the jobs, housing, and entertainment uses had been located in Boston's suburbs.